The Journal of

THE ROYAL AERONAUTICAL SOCIETY

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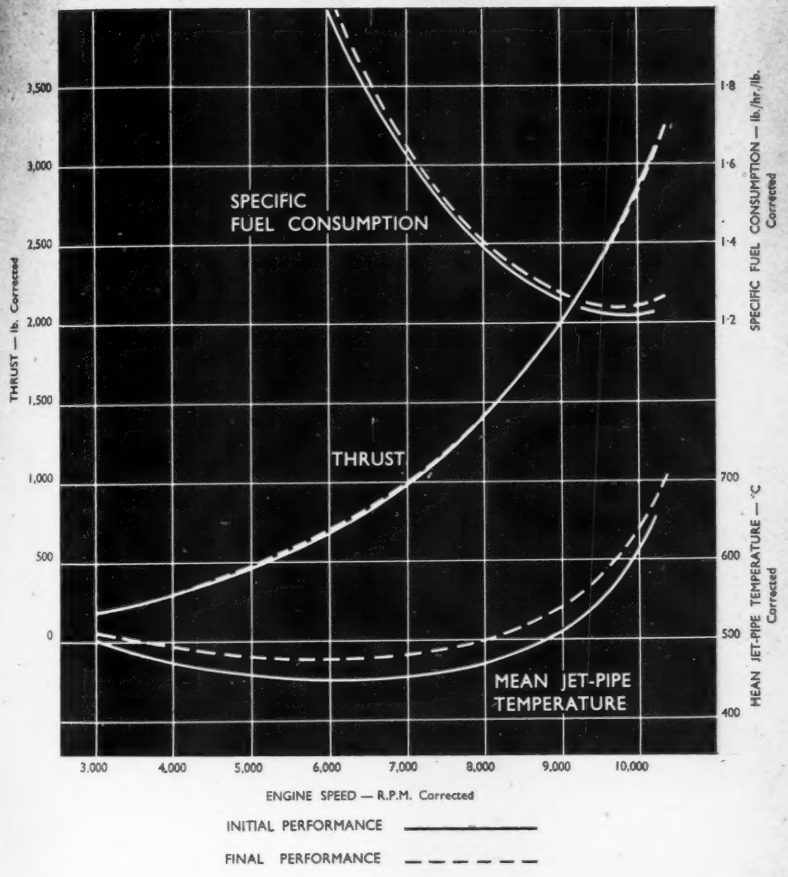

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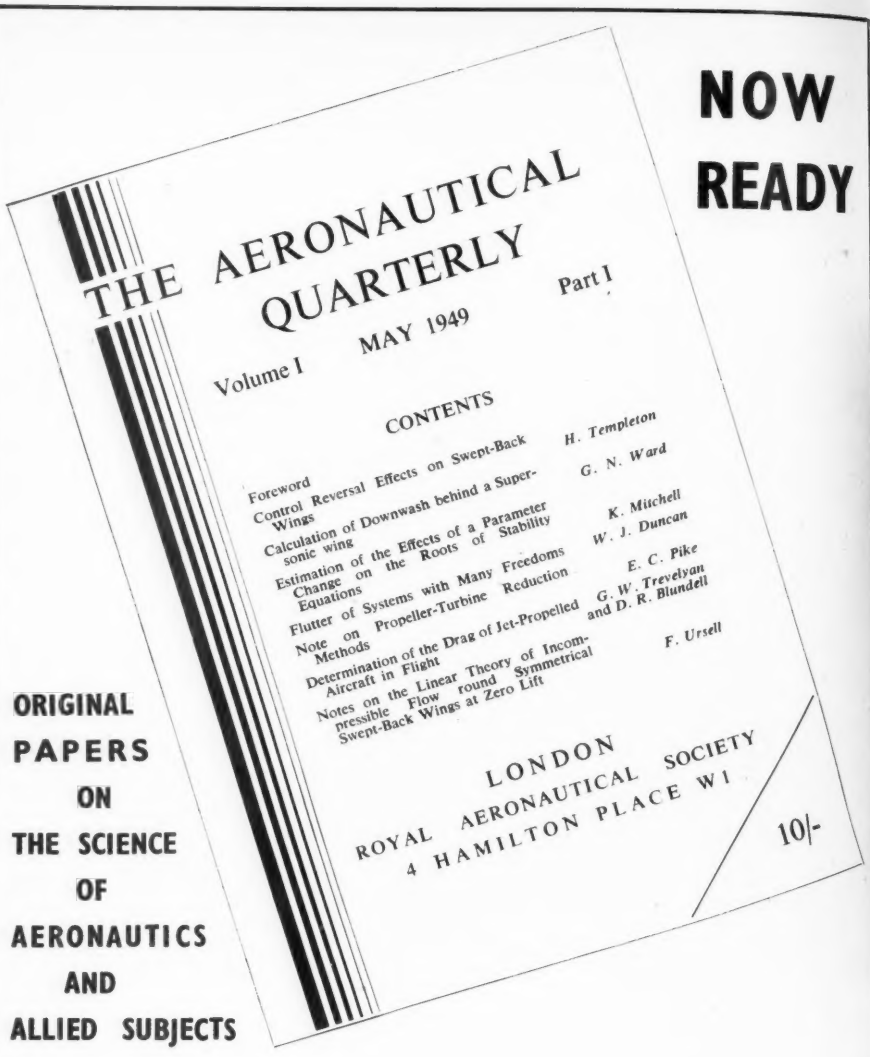
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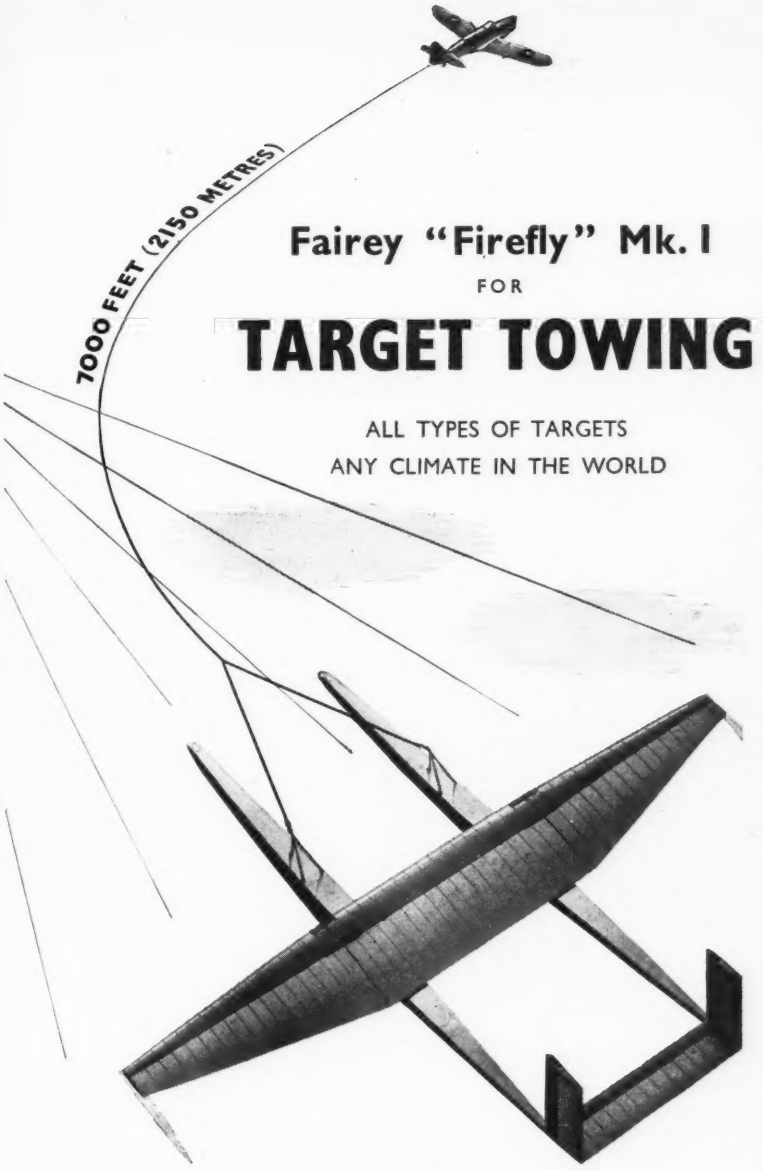

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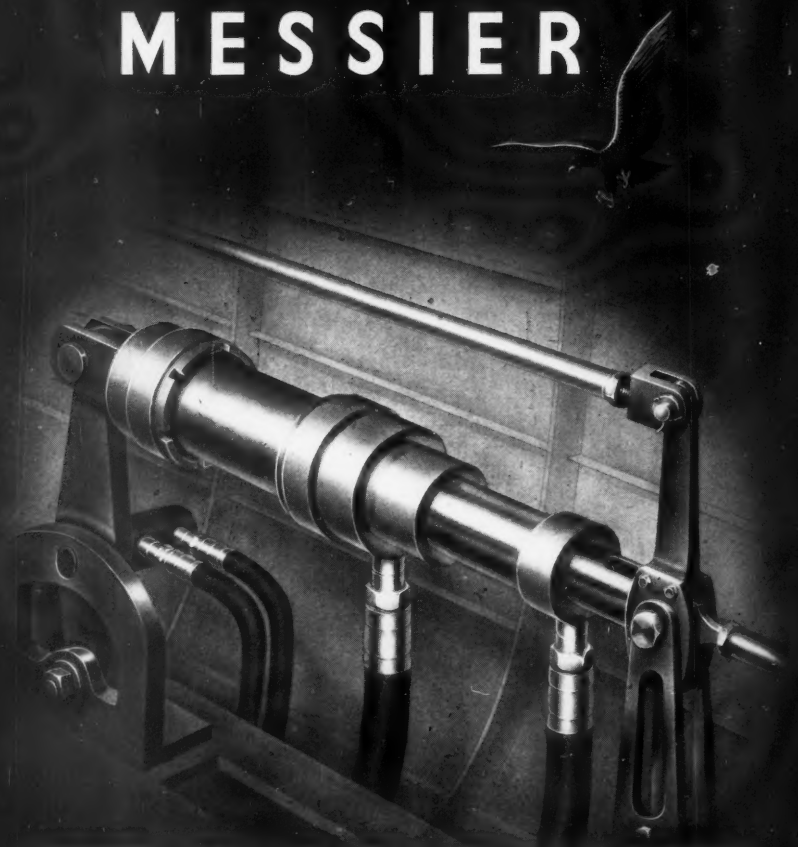

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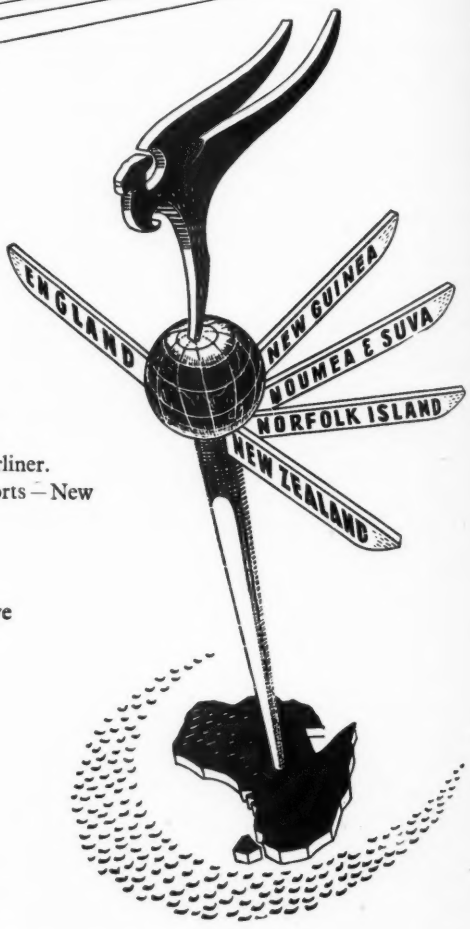

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Awarded for work leading to advance in aeronautics.

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Awarded for outstanding practical achievement leading to advancement in aeronautics.

British Silver Medal for Practical Achievement in Aeronautics

Awarded for practical achievement leading to advancement in aeronautics.

Wakefield Gold Medal

Awarded annually, at the discretion of the Council, to the designer or inventor of any apparatus tending towards safety in flying.

The George Taylor (of Australia) Gold Medal

Awarded annually, at the discretion of the Council, for the most valuable paper read during the previous session.

Simms Gold Medal

Awarded annually, at the discretion of the Council, for the most valuable contribution read before, or received by, the Society on any subject allied to aeronautics, *e.g.* structures, meteorology, metrology, etc.

Herbert Akroyd Stuart Memorial Prize

Awarded at the discretion of the Council for the most valuable contribution read before, or received by, the Society on applied thermodynamics.

Edward Busk Memorial Prize

Awarded annually, at the discretion of the Council, for the most valuable contribution read before, or received by, the Society on applied aerodynamics.

Orville Wright Prize

Offered annually for the best contribution on some subject of a technical nature in connection with aeronautics, which is received by the Society and published in *The Aeronautical Quarterly*.

Pilcher Memorial Prize

Awarded annually, at the discretion of the Council, for the most valuable paper read by a Graduate or Student during the previous year at any meeting of the Society or its Branches.

Usborne Prize

Awarded annually, at the discretion of the Council, for the best contribution to the Society's publications written by a Graduate or Student on some subject of a technical nature in connection with aeronautics.

R. P. Alston Memorial Prize

Awarded for practical achievement associated with the flight testing of aircraft.

Major Baden-Powell Memorial Prize

Awarded to the best entrant in the Associate Fellowship Examination.

Wilbur Wright Memorial Premium

The Wilbur Wright Memorial Lecture is held annually, a premium of £75 being awarded to the lecturer, if British, or £125 if he is an American, invited by the Council to deliver the lecture. The lecture is usually given alternately by an American and an Englishman, and is the most important aeronautical lecture of the year.

British Commonwealth and Empire Lecture

The British Commonwealth and Empire Lecture is delivered annually by a lecturer chosen in alternate years from the British Dominions and Colonies and Great Britain.

The British Commonwealth and Empire Lecture has a premium of £50 and in the case of lecturers from the Dominions and Colonies an allowance is paid towards the lecturer's expenses.

Branch Prize

The Council offer an annual prize of twenty guineas for the best paper read before the Branches during the previous lecture session. The prize is open to any member of the Society or of any Branch.

37th Wilbur Wright Lecture

THE AERONAUTICAL RESEARCH SCENE —GOALS, METHODS AND ACCOMPLISHMENTS

by

HUGH L. DRYDEN, M.A., Ph.D., F.R.Ae.S., Hon.F.I.Ae.S.

PRIZES were presented and The Thirty-seventh Wilbur Wright Lecture was delivered before The Royal Aeronautical Society at the Royal Institution, 21 Albemarle Street, London, W.1, on Thursday 28th April 1949. Dr. H. Roxbee Cox, B.Sc., D.I.C., F.I.Ae.S., F.R.Ae.S., President, presided at the meeting.

The President: Before proceeding with the main business of the evening—the Wilbur Wright Lecture—he had the pleasant duty of presenting some of the Society's medals, prizes and fellowships:—

The British Gold Medal: Awarded for outstanding practical achievement leading to advancement in aeronautics, to Mr. S. Camm, Director and Chief Designer, Hawker Aircraft Ltd., whose work was well known.

The British Silver Medal: Awarded for practical achievement leading to advancement in aeronautics, to Lieutenant Commander E. M. Brown, R.N., for his work towards advancement in the technique of deck landings.

The Society's Bronze Medal: The Society awarded its own gold, silver and bronze medals, but they were presented only on rare occasions and only for the most outstanding achievements. For the past year neither the gold nor the silver medal had been awarded, but award of the bronze medal for work leading to the advancement of aeronautics had been made to Captain R. N. Liptrot, for his work over many years in connection with helicopters.

The Wakefield Gold Medal: Awarded annually at the discretion of the Council to the designer or inventor of any apparatus tending towards greater safety in flying, to Mr. E. S. Calvert for his work on the development of airport lighting, about which the Society had heard in his recent lecture.

The George Taylor of Australia Gold Medal: Awarded annually at the discretion of the Council for the most valuable paper read during the previous session, to Mr. G. R. Edwards for his paper on Problems in the Development of a New Aeroplane, one of the most successful and valuable papers ever delivered before the Society.

The Edward Busk Memorial Prize, awarded annually at the discretion of the Council for the most valuable contribution on Applied Aerodynamics read to or received by the Society, to Mr. W. Stewart for his paper on flight testing of helicopters.

The Herbert Akroyd Stuart Memorial Prize, which was rarely awarded, was for the most valuable contribution on Applied Aerodynamics read to or received by the Society, and was earned last year by Mr. W. H. Lindsey for his paper on The Development of the Armstrong Siddeley Mamba Engine.

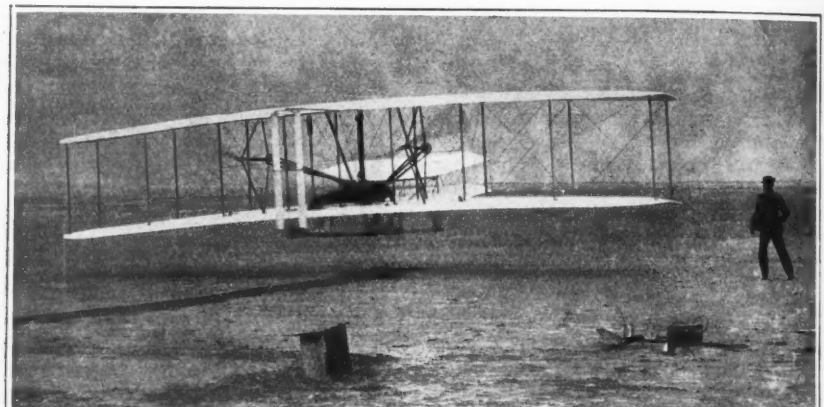
The Usborne Prize: Awarded for the best contribution to the Society's publications written by a Graduate or Student on a subject of a technical nature in connection with aeronautics, to Mr. D. R. McGuire for his paper on enemy jet history.

The R. P. Alston Memorial Prize: Awarded for practical achievement associated with the flight testing of aircraft, to Mr. B. A. G. Mcgowan for his work on the flight testing of gliders.

The Baden Powell Memorial Prize for the best result in the Associate Fellowship examination was awarded to Mr. R. J. Starling.

Honorary Fellowships: He had great pleasure in announcing that Honorary Fellowships of the Society had been awarded to Lord Brabazon, Sir Frederick Handley Page and M. Louis Breguet.

He now came to the main event of the evening.



The first controlled and sustained flight, 17th December 1903, Orville Wright piloting the machine; Wilbur Wright on foot.

It was a long time since the Society had presented a Wilbur Wright Lecture in the lecture hall of the Royal Institution, and on the last occasion the lecturer had also been an American, Colonel Lahm. It was particularly appropriate that the current Wilbur Wright Lecture should be delivered at the Royal Institution because the President of that great Institution was also a member of the Council of the Royal Aeronautical Society; in fact, he was a member of Council before he became President of the Royal Institution; both that Body and the Royal Aeronautical Society had gained distinction from their association with Lord Brabazon.

Every President of the Society faced the temptation of opening a Wilbur Wright Lecture with a concise précis of its origin and constitution. So many—including himself—had fallen to that temptation, that he made no excuse for omitting the formal history from his preamble on this occasion. It was well known to all. It was sufficient to say that the Wilbur Wright Lecture was unique in aeronautical history; it conferred distinction upon those who gave it and they, already distinguished, year by year enhanced its stature.

The latest in a long series of eminent Americans to give the Wilbur Wright Lecture was Dr. Hugh L. Dryden, who was once again welcomed to Great Britain. They were always glad to see him, and the Society was more than glad to have the opportunity to honour him by inviting him to give the Wilbur Wright Lecture.

Dr. Dryden was a very eminent person—Past President of the Institute of the Aeronautical Sciences and a Fellow of the Royal Aeronautical Society. After a distinguished career in the Bureau of Standards he became in 1947 Director of Aeronautical Research to the National Advisory Committee for Aeronautics in America.

His lecture was on the "Aeronautical Research Scene—Goals, Methods and Accomplishments." The Scene was vast—and he knew it well; as to the Goals, it was well known that he had scored a good many of them himself; for many of the Methods, he had been responsible. In his Accomplishments in that field he had no rival. They looked forward to the presentation of his lecture with the greatest pleasure.

INTRODUCTION

The Council of the Society has greatly honoured me by inviting me to read the Wilbur Wright Memorial Lecture in 1949. This is the thirty-seventh occasion on which the Society has assembled to honour Wilbur Wright by listening to a review of some aspect of the vast field of aeronautics which has been erected on the foundation of the achievements of Wilbur and his brother. Orville Wright lived to see the dawn of the supersonic age, beginning a new era of development of high-speed transport, whose potentiality for the good of mankind is as unlimited as its potentiality for harm. Neither could possibly have foreseen either the rapid progress in aircraft size and performance, or the impact on our civilisation of their activities at Kitty Hawk, North Carolina, on 17th December 1903.

It is beneficial to aeronautical scientists and engineers to be reminded periodically that Wilbur and Orville Wright achieved success as a result of keen intellectual effort and hard work, and not by some chance inspiration. They devised new instruments of research; they conducted extensive experimental programmes in wind tunnel and flight; they studied problems of aerodynamics, thermodynamics, and structural design; they applied the results to the design of a practical aeroplane; and they had the immense satisfaction of successful flight. To-day as then, the intellectual resources and leadership of the scientist and engineer are essential to progress in aeronautics.

The Royal Aeronautical Society deserves great credit for its vision in inaugurating these memorial lectures. As you all know, this tradition has been adopted by the Institute of the Aeronautical Sciences in the establishment of the Wright Brothers Lecture, which has been given on many occasions by eminent members of the Society. These lectures have been a strong bond not only between the Society and the Institute, but also between our two nations.

We in the United States are deeply conscious of the debt we owe to your scientists, engineers, and pilots. I need only mention the names of Lanchester, Bryan, Bairstow, B. M. Jones, and G. I. Taylor, to remind you of advances in aeronautical science recognised as milestones throughout the world. The name of Frank Whittle recalls your generosity in making available to our military services the prototype of the new power plant, which has created a technical revolution in aeronautics. The valiant deeds of the men of the Royal Air Force during World War II, in holding the line until our strength could be mustered, will not soon be forgotten.

On behalf of the Institute of the Aeronautical Sciences I may say that we look forward to the occasion next month when we shall be your hosts in the United States, and we hope in some measure to return the hospitality extended by the Society and its friends to us last year. I hope to welcome many of you at the laboratories of the National Advisory Committee for Aeronautics, as you have welcomed me to your establishments and factories.

The subject of research has been dealt with many times in the series of Wilbur Wright Lectures. In 1923 Joseph S. Ames, former chairman of N.A.C.A., described the equipment of the Langley Aeronautical Laboratory and the progress of investigations on the distribution of air loads on aeroplanes and airships and on scale effect in aerodynamic measurements. Nine years later H. E. Wimperis discussed the organisation of research in Great Britain and described the newly-available wind tunnels and seaplane tank. Ten years ago my predecessor, G. W. Lewis, described the trend of wind tunnel development in the United States and discussed research on

gust loads and on stability and control. In 1944 W. S. Farren devoted the Seventh Wright Brothers Lecture before the Institute of the Aeronautical Sciences to the planning and application of research for aeronautics. I shall follow these general patterns and discuss some of the more prominent highways of the aeronautical research scene of to-day which lead toward the horizons of the future and to the more immediate goal of better aircraft soon.

THE AERONAUTICAL RESEARCH SCENE

The aeronautical research scene of ten years ago when Dr. Lewis addressed you was very different from that of to-day. The DC-4 had just made its demonstration flights. The B-17 and the P-40 were our promising military aircraft, and the speed record of 440 miles an hour was held by Italy. The N.A.C.A. had one laboratory at Langley Field, with about 500 employees. Laminar-flow aerofoils, turbulence effects in wind tunnels, and stalling of tapered wings, were typical aerodynamic subjects of interest. The word transonic was not yet born, and supersonic speeds held the interest only of ballisticians and a few enthusiasts, who pointed to the practical problem of the aerodynamic characteristics of propeller sections at high speeds. Compressibility effects, however, were being encountered and studied in the N.A.C.A. eight-foot 500 m.p.h. wind tunnel. New forms of cowling, windshields, and propellers, were being developed to delay the onset of shock waves. Powerplant research was occupied with wear of piston rings and cylinders, fuel injection, octane rating, vapour lock, cowling and cooling, close-finned cylinders. Research on problems of diesel engines was still considered worth while.

The most prominent features of the aeronautical scene to-day are associated with transonic and supersonic aerodynamics and jet propulsion.. Research directly related to reciprocating engines has contracted to a very small region. The new power plants represent such a fusion of aerodynamics and thermodynamics that the boundaries between aerodynamics and propulsion are ill defined, although the special field of rockets is a well-recognised speciality. Subsonic aerodynamics has not diminished in area, since the high-speed aircraft must operate safely in this region as well as at transonic and supersonic speeds. The contact of high-speed aerodynamics and structures has precipitated an area of aeroelastic problems. New aerodynamic configurations have reorientated structural research. Materials research is dominated by the need for improved high-strength heat-resisting alloys.

Within the field of aeronautical research we find much human activity; a great army of research workers moving across the scene along many highways in many types of vehicles and with many aims. The general objective of all this activity is, as Farren stated, the discovered of how to make better aircraft. Research is the foundation for the quality of the aircraft. From N.A.C.A. experience the quality of the aircraft to be manufactured four years from now depends on the experimental facilities begun four years ago and on the research now being started. The activities included under the term "research," and the goals of various groups of research workers have become widely varied. It has long been known to scientists and engineers that the best method of advancing a practical field is to set different goals before different groups.

The setting of practical goals has little value in the field of that type of research called pure, basic, or fundamental, by various writers, in which the worker himself cannot foresee the possible applications or evaluate their true worth. The most common goals of basic research are discovery and understanding. The path between basic research and the finally-developed product is not a direct one. The same basic-research accomplishment may contribute to improvements in many products, and the improvement of any particular product depends on the results of basic research in many fields. Nevertheless it is possible to guide even this type of research into areas which bring productive results to a given technological field.

By contrast, it is profitable to set specific goals for groups conducting applied research directed toward specific applications. The result may be an invention or the construction of prototype equipment meeting the specific goal. Such a research group draws upon all the existing knowledge obtained by basic research and can suggest new problems for basic research.

There are many other groups engaged in aeronautical research travelling intermediate roads. In general the basic-research groups

yield results which will be applied to aircraft of the future whereas the applied-research groups look toward early application. We shall consider briefly some typical examples of the goals, methods, and accomplishments of six types of aeronautical-research groups, engaged in (1) the exploration of new fields, (2) the search for understanding, (3) the search for and evaluation of test methods and procedures, (4) the systematic survey of a limited field, (5) the preparation of a foundation for an advanced technical development, and (6) the support of specific applications.

EXPLORATION OF NEW FIELDS

CONTRIBUTION OF THEORY

The most important tool in aeronautical research, even more important than large wind tunnels, is the human mind. There is a large group of aeronautical research workers who apply their conceptual and logical faculties to the exploration of new fields. When checked and guided by suitably planned experiments, the theories developed by this group become the foundation for prediction and analysis of results to be expected in experiments yet to be made.

Theories need not be perfect or universally applicable to be useful, provided that their limitations are clearly understood. One of the surprising developments in aeronautics is the wide utility of the potential theory of a non-viscous fluid. A few decades ago classical hydrodynamics was considered as a purely mathematical discipline, having little or no connection with the behaviour of a real fluid. The practical field of hydraulics was based almost completely on empirical experiments with little underlying theory. With the advent of the aeroplane, and experimentation on its component parts, it was found that predictions made on the basis of the mathematical potential theories of classical hydrodynamics were strikingly accurate in many instances, especially as bodies of better aerodynamic form were discovered. As a result, aeronautical engineers have developed a considerable degree of confidence in the predictions of potential theory.

As the velocity of the tips of aeroplane propellers and later of the complete aeroplane increased, it became necessary to consider the effects of the compressibility of the surrounding air. Again the early theoretical workers turned to potential theory, but this time they were confronted with a very difficult non-linear partial differential equation. To make the problem more amenable to analysis, Prandtl, in the early twenties, proposed a linearisation of this equation based on the assumption that the flow around a thin wing or streamlined body may be considered as a small perturbation field superimposed on a uniform free stream. Soon afterwards followed the two-dimensional subsonic aerofoil theories of Glauert and Prandtl, and the two-dimensional supersonic theory of Ackeret.

The decade of the thirties extended the range of interest to problems concerning bodies of revolution, and saw the birth of some of the notions to be later found so useful in supersonic three-dimensional wing theory. The concepts of a supersonic source and doublet were adopted from the basic theory related to the wave equation of mathematical physics and applications were extended to include inclined bodies of revolution. The general ideas of conical-flow field evolved from the work of several theorists.

The forties saw an extreme growth in the rate of development of supersonic theory. In particular, supersonic, three-dimensional wing theory sprang into being nearly overnight. Several schools of thought arose; one based on the conical-flow concepts of Busemann, another on the source, sink, and doublet concepts, and another on the use of Fourier integrals and the acoustic analogy. All were exploited by a great number of theoretical workers, and often a new theoretical result was simultaneously discovered by several independent workers.

The trend of investigation at the present time is in the direction of developing more accurate wing theories by including previously-neglected non-linear terms and by including terms representing viscous forces. Non-steady flows are also receiving much attention for use in analysis of flutter, gust loads, and aeroplane dynamics. The accomplishments of the theoretical workers in this and related fields have been summarised recently by von Kármán[1] and by Lighthill[2].

Many of the theoretical problems of modern aeronautical research are not amenable to exact mathematical treatment, either because the numerical computations, although straightforward in principle, are extremely laborious, or because processes of

numerical or graphical approximation are the only methods of attack. The development of modern, large-scale, high-speed computing machines makes possible an attack on both types of problem. Such machines are usually classified as either "analogue" or "digital" machines. The analogue machine is not strictly a computing machine, but rather a direct physical analogue of the system being studied. Electrical and electronic analogue computers have recently been developed on a commercial scale, and have been found useful in problems of aeroplane dynamics, heat transfer, and so on. The analogue machines are capable of solving both linear and non-linear systems of ordinary differential equations with high speed and limited accuracy.

The digital machines have a wider application. As the name implies, they perform the elementary arithmetical operations of addition, subtraction, multiplication, and division. The culmination of this line of development is the electronic digital computer, the first of which, the E.N.I.A.C., is now being operated at the Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland. Extensive systems of simultaneous linear algebraic equations become tractable with such machines. Present numerical methods of solving partial differential equations become practicable when the speed of operation reaches the values now contemplated by machine designers.

The E.N.I.A.C. has already been applied to several aerodynamic problems, for example, flow in compressible boundary layers[3]. At present it is completing computations of the supersonic-flow field around cone-cylinder combinations with attached shock wave.

The prominent position held by theoretical workers in supersonic aerodynamics in the present aeronautical research scene is due in part, at least, to the large, expensive, and complicated equipment required to make experimental measurements, and to the confidential status of most of the experimental results.

TRANSONIC COMPRESSIBLE FLOW

One of the problems on which much exploratory work is in progress is that of transonic flow in which there are regions of both purely supersonic and subsonic flow. Difficulty is encountered by the theorist since the partial differential equation with which he works changes character in the field; and, of necessity, solutions obtained in the subsonic and supersonic portions of the flow must match on the boundary. The available mathematical knowledge is insufficient. Moreover, experimentation has not yet established clearly the extent to which the fluid can be idealised. In two dimensions the inter-action of shock waves existing in the field with the boundary layer is known to depend on the Reynolds number, the type of shock-wave formation being different depending on whether the flow in the boundary layer is laminar or turbulent. These variations produce differences in the pressure distribution on aerofoils, but it is not definitely known whether an adequate treatment can be achieved without the inclusion of viscous effects.

Tsien and Finsten[4] presented a paper recently which indicates that some of the principal features of the inter-action may be accounted for without introducing viscous effects. They studied an idealised case consisting of a subsonic flow of uniform velocity of limited depth along a plane solid boundary and a supersonic flow extending from the outer boundary of the subsonic stream to infinity. The behaviour of the system was studied (1) when a shock wave in the supersonic flow was reflected from the boundary between subsonic and supersonic flow, and (2) when there was a small disturbance at the wall. The effects propagate upstream in the subsonic region to a distance which is proportional to the thickness of the subsonic layer. The authors suggest that the principal difference between the shock-wave boundary-layer inter-action for laminar and turbulent boundary layers, lies in the thickness of the subsonic-flow region which is much less for the turbulent case.

RAREFIED-GAS FLOW AND HYPERSONIC FLOW

Among the most interesting explorations in aeronautical research are those being conducted in the fields of rarefied-gas flow and hypersonic flow. Interest in these fields arises from the directions of development of jet power plants and missiles. Missiles have already penetrated to extreme altitudes in the atmosphere and it is well known that the power required for supersonic flight is greatly reduced as the altitude is increased. There is every practical incentive to develop air-breathing jet-propulsion devices capable of operation at very high altitudes. A research programme which looks to the future must

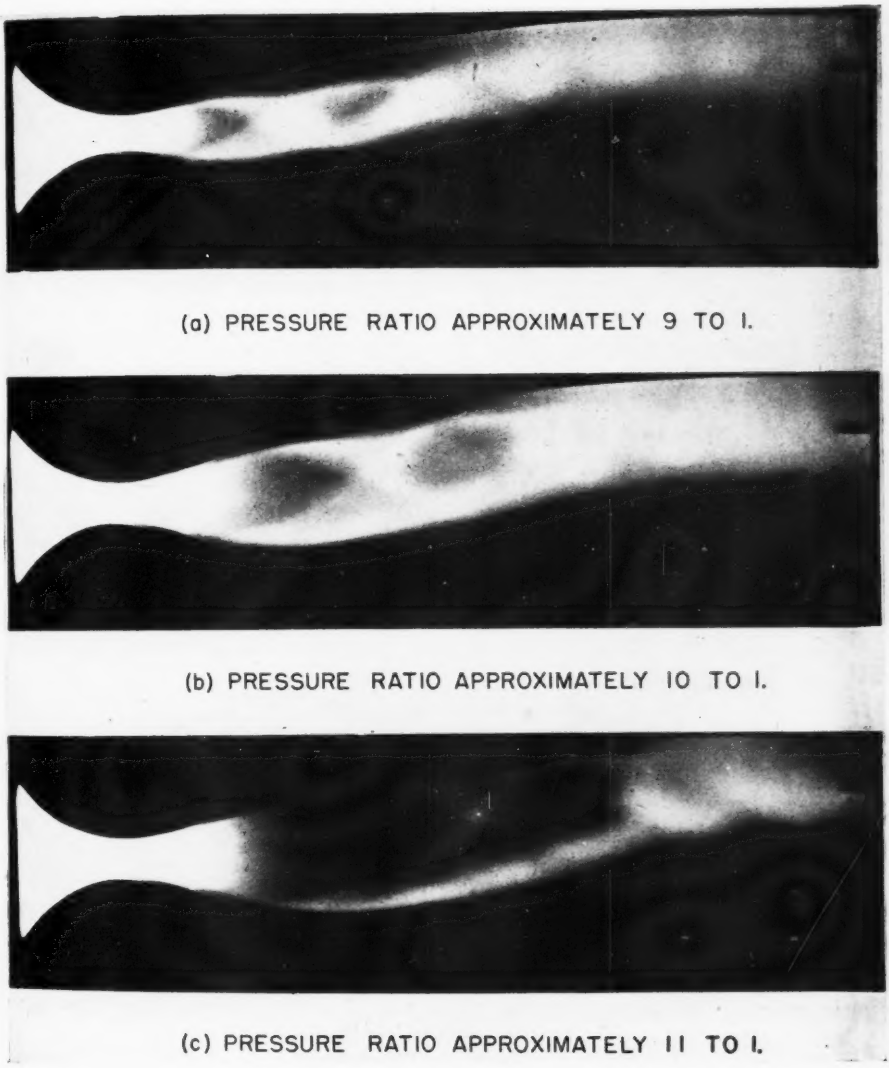


Fig. 2.

Photographs of a stream of glowing nitrogen with a stagnation pressure of approximately 20 millimetres of mercury. (The nozzle does not fill for these pressure ratios.)

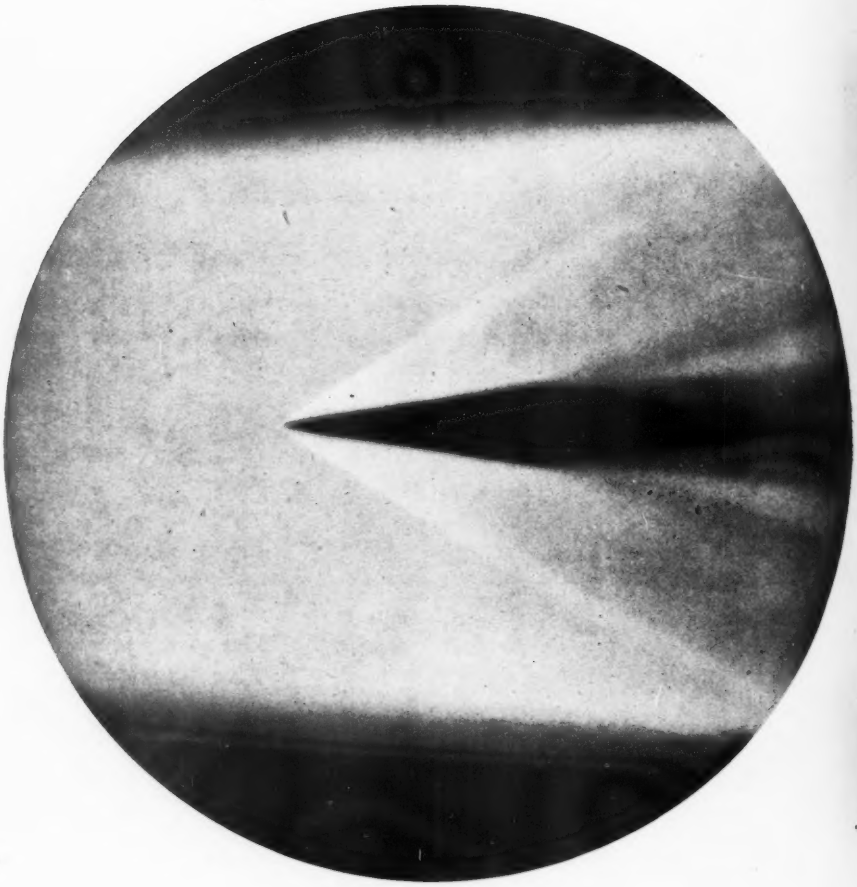


Fig. 3.

Photograph of after-glow pattern over a 15° double wedge (stagnation pressure 60 mm. Hg, Mach number 2.6).

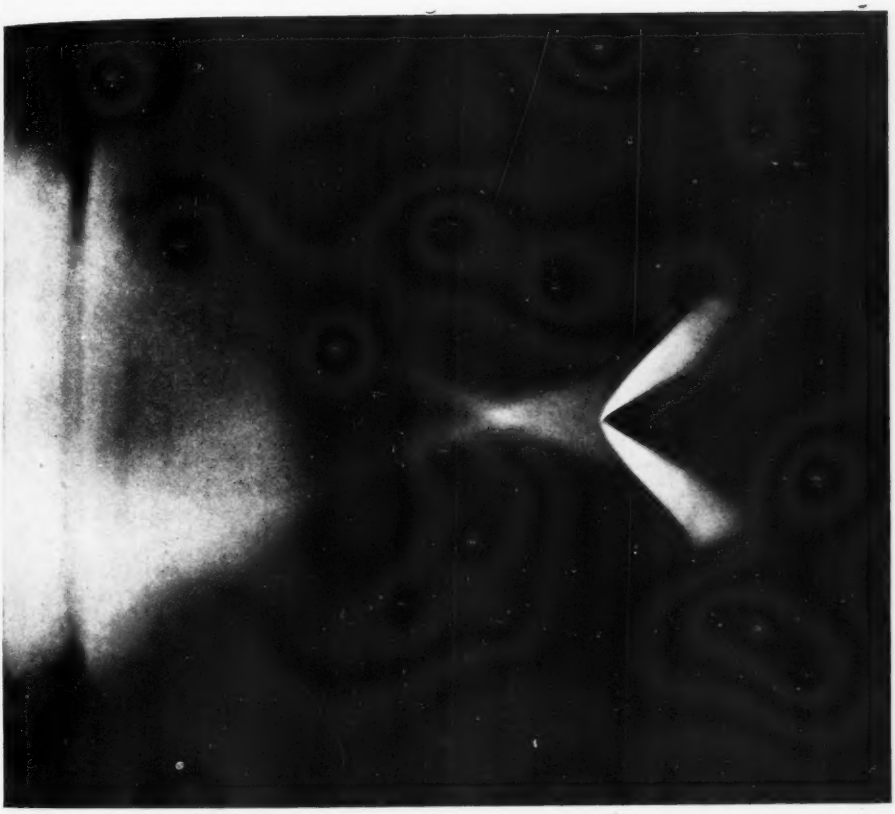


Fig. 4.

Photograph of after-glow pattern over a 50° wedge in a stream from a conical nozzle. (Note shock waves from nozzle. Stagnation pressure 140 microns Hg, Mach number 2.)

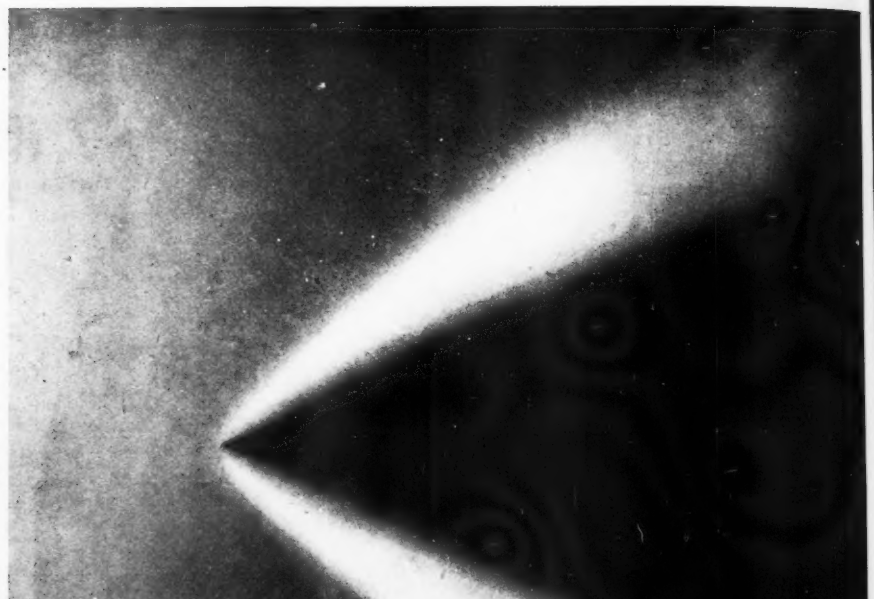


Fig. 5.

Photograph of after-glow pattern over a 30° wedge in a shock-free stream. (Stagnation pressure 140 microns Hg, Mach number 2.)

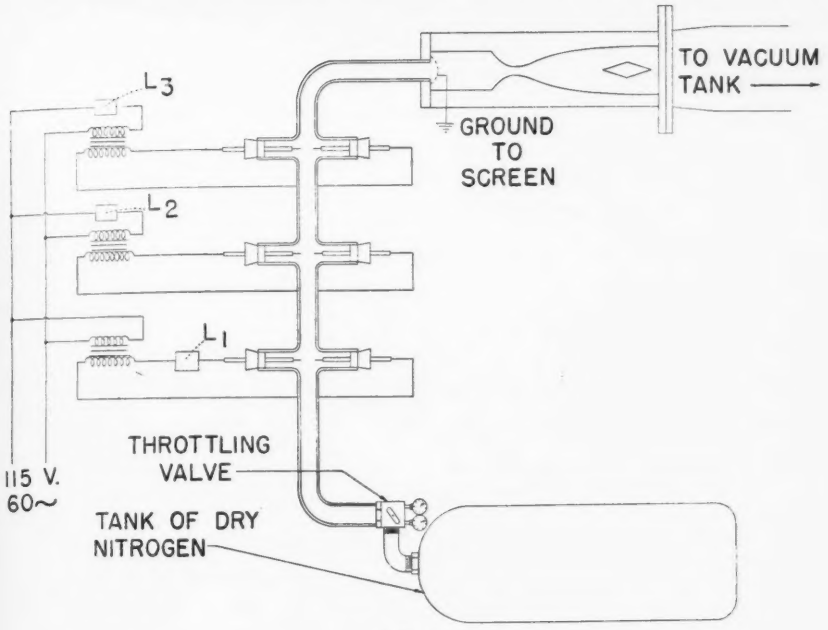


Fig. 1.
Sketch of apparatus for producing after-glow in a supersonic stream of nitrogen.

give some attention to basic work in this area. The development of the V-2 and other rockets has permitted the physical exploration of the upper atmosphere. In time this work will give definite quantitative information on the physical conditions existing there. As in any exploring expedition, entirely new and unexpected phenomena may or may not be encountered, but it is known that the conditions include very low pressure and density. It is also inferred that the low pressure and density indicate greatly reduced drag of bodies moving through the upper atmosphere, and hence the possibility of greatly increased speeds. For this reason some small-scale exploratory work is in progress in which the conditions of low pressure and density are reproduced in laboratory apparatus. Kane and Folsom[5] have recently reported some pioneering work in this field. Some work is also under way in N.A.C.A. laboratories.

Tsien[6,7] has summarised the theoretical background which enables a classification and separation of the flow problems. At low pressures and densities, the fluid can no longer be treated as a continuum and the ratio of the mean free path of the molecules to the boundary-layer thickness becomes a controlling parameter. If this ratio is less than 1/100, the usual compressible-flow equations are valid. If the ratio is larger than 10, the gas may be considered as a stream of free molecules colliding with the wall. Between these limits the gas slips over the surface, as investigated by Maxwell in 1879, and hence this region is called the slip-flow region. In any of these regions the Mach number may be high or low.

The distinction between supersonic and hypersonic flows is an arbitrary one. From the theoretical point of view there are important simplifications[8] at extremely high Mach numbers, where the Mach lines lie almost parallel to the flow. From the experimental point of view, the attempted realisation of very high Mach numbers may lead to low density and to flows in the slip region, as well as to difficulties with condensation of the fluid. Thus there is often some confusion between the problems inherent in hypersonic flows and in low-density flows.

An important tool has recently been developed for the qualitative study of flows at low density. It is the after-glow in a gas of low density when excited by an electrical

discharge. The method was proposed by Joseph Kaplan, of the University of California, and applied by Williams and Benson[9] of the N.A.C.A. Langley Laboratory and Stalder and Goodwin of the N.A.C.A. Ames Laboratory.

Figure 1 shows the apparatus used by Williams and Benson to produce after-glow in a supersonic stream of nitrogen. Fig. 2 shows photographs of a stream of glowing nitrogen in a nozzle which does not fill for any of the pressure ratios shown. Fig. 3 shows the flow past a 15° double wedge at a test-section static pressure of 3 mm Hg (stagnation pressure 60 mm Hg) and a Mach number of 2.6 as shown by the after-glow technique. Comparisons with schlieren photographs at stagnation pressures of 120 to 180 mm Hg show good qualitative agreement in the shock-wave formations.

Figures 4 and 5 show after-glow photographs in nitrogen taken by Stalder and Goodwin at a test-section static pressure of 140 microns Hg and Mach number of 2.

After-glow is a term descriptive of the luminescence that persists in certain gases for an appreciable time after the gases are excited to states capable of emitting light. The time may vary from microseconds to hours. The intensity increases with the density, but the quantitative relations have not been fully explored. Impurities affect the phenomenon, and there are thermal and possibly other effects of the excitation that need further exploration. Enough work has been done to show that this method may serve the function at low density performed by smoke-flow observations at low speeds, and schlieren observations at high speeds in streams of higher density.

Plastic Flow of Materials

Exploratory research is not confined to aerodynamics. Space permits but one additional illustration, the field of plastic flow. Much theoretical research has been conducted on plastic flow with the objective of determining the time history of the stress and strain at all points in a body of arbitrary shape, when the boundary loadings and displacements are known at all times. Difficulties arise in the attempt to generalise the observed stress-strain relations for simple tension and compression to complex loading conditions when some or all of the material is loaded beyond the elastic range. The numerous theories may be classified into two principal types. One type, called deformation theories, assumes that the state of strain is uniquely determined by the state of stress, following the non-linear elastic stress-strain curve unless unloading occurs. The other type, flow theories, assumes that increments in permanent strain are determined by stress and strain increments. Both assume that unloading follows the elastic stress-strain curve. Whether the change in the stress state causes unloading or loading is supposed to depend upon whether the change increases or decreases a rotationally invariant function of the stress. Additional assumptions are required to construct a definite theory; Prager[10] and Drucker[11] at Brown University have reviewed the several theories.

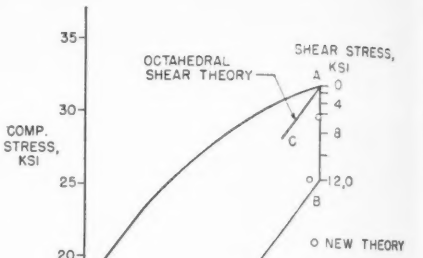


Fig. 6.
Compression stress-strain relations for cylinder subjected to compression and torsion.

At the N.A.C.A. Langley Laboratory work has been in progress on the problem of the plastic buckling of plates. In the course of this work Batdorf[12] and his colleagues encountered certain paradoxical results which led Batdorf and Budiansky[13] to propose a new theory of plasticity based on the concept of slip. The new theory assumes that all plastic deformation is due to slip which occurs first along the plane of maximum shear stress in the direction of this stress at the moment the elastic limit for the material is exceeded. As the stress continues to increase, the slip along this plane increases and slip begins along adjoining slightly-inclined planes as the shear stress on them goes above the elastic limit. The theory assumes that slip occurs along every plane and in every direction in those planes in which the corresponding shear stress component is large enough to cause slip.

An experiment somewhat like one proposed by Drucker was conducted, in which

a cylinder was compressed beyond the elastic range and was then twisted while holding the compressive strain constant. The essential data are shown in Fig. 6. Throughout the twisting process (AB in the figure) the compressive stresses decreased while the shear stresses increased. The plastic part of the compressive strain continually increased. Simple calculations show, however, that during the early part of the twist both the octahedral shear stress and the maximum shear stress were decreasing. According to conventional theories, the stress and strain should have been elastically related as indicated by the line AC. The predictions of the new theory as to the compressive strain associated with the applied stresses are in far better agreement with experiment than with the predictions of the flow and deformation theories.

SEARCH FOR UNDERSTANDING

When the tools of the theoretical worker and of the experimental worker are applied to the same problem, each accommodating his attack to that of the other, there results the type of research which has the greatest potentiality for the guidance of future practical applications. The object of such research is the understanding of the phenomena which occur in the flow of actual fluids. Some practising designers who use the concepts of boundary layer, laminar flow, turbulent flow, transition, and separation, may need occasionally to be reminded that these concepts did not always exist, and that a great debt is owed to L. Prandtl and the Göttingen school, but most designers realise that a deeper understanding of transition and flow separation offers the only hope of substantial advances in the performance of aircraft. Therefore groups which show aptitude for this type of attack and are stimulated by this statement of the goal should be supported. The N.A.C.A. is supporting groups of this character at several universities and in its own laboratories.. We are pleased to see that the Ministry of Supply and the Aeronautical Research Council are building up similar centres in Great Britain, and we look forward with interest to the reports from Manchester, Cambridge, Imperial College, and similar centres, as well as from the basic research groups at Teddington and Farnborough.

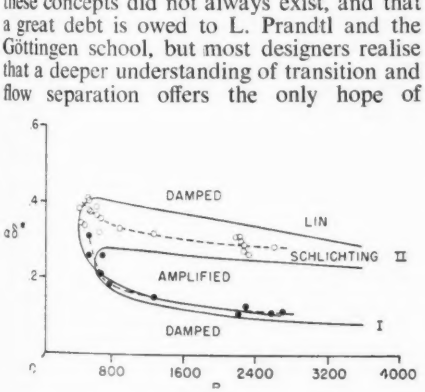


Fig. 7.

Instability boundary from observed wave lengths for zero damping of disturbances in Blasius velocity distribution compared with theoretical curves of Schlichting and Lin. ($2\pi/\alpha$=wave length, δ^*=displacement thickness of boundary layer.)

ORIGIN OF TURBULENCE

One of the problems on which great progress has been made in the past decade is the origin of turbulence. Much theoretical work of an exploratory character was done by German investigators, notably Heisenberg, Tollmien, and Schlichting, on the assumption that laminar flow was unstable at a sufficiently high Reynolds number. More accurately, small disturbances were superposed on the laminar velocity distribution and their subsequent behaviour investigated. It was found that small disturbances of wave length lying within certain limits are amplified, whereas disturbances of shorter or longer wave lengths are damped, provided that the Reynolds number of the boundary layer is greater than a certain critical value.

For many years the available experimental data seemed to contradict this result. It is now known that the turbulence of the air streams in which the experiments were made was so great that these external disturbances controlled transition. Schubauer and Skramstad[14] succeeded in reducing the initial turbulence of their air stream in following the same procedure experimentally, as the mathematicians had done theoretically. They devised a method of introducing controlled small disturbances of known frequency and of studying the behaviour downstream. Their results confirmed the Tollmien-Schlichting theory in every respect. Fig. 7 shows one of the comparisons.

Lin, at the California Institute of Technology, extended and revised the mathematical theory of Schlichting, clarifying the behaviour of the differential equation in the neighbourhood of the singularities and recomputing the numerical values. German theoretical workers extended the theory to

many other cases, including the velocity distributions found in flows with pressure gradients, both accelerating and decelerating, and flows with distributed suction. Meksyn, at King's College, London, studied the mathematical problems involved and made independent computations for several additional flows. Lessen, at the Massachusetts Institute of Technology, computed the stability of the laminar boundary layer between parallel streams, finding a much lower critical Reynolds number than for the Blasius distribution. Several summaries are available[15, 16, 17] but the subject has progressed so fast that none are complete as of to-day.

The Tollmien-Schlichting waves do not constitute turbulent flow, and according to the theory there will be no amplified wave unless small initial disturbances are present. It is believed, but not definitely proved as yet, that the waves of increasing amplitude produce intermittent separation in the regions of adverse pressure gradient, and that the intermittent separation produces dynamically unstable vortex sheets, which roll up into eddies of dimensions which are small compared to the thickness of the boundary layer. These diffuse rapidly throughout the layer. If the free-stream turbulence is greater than 0.2 per cent., the stream turbulence is accompanied by adverse gradients sufficiently great to produce transition according to G. I. Taylor's theory, in which the intensity and scale of the turbulence are controlling. At low free-stream turbulence, the initial disturbances are selectively amplified so that the Tollmien-Schlichting waves appear. In the limit, noise or surface roughness will be the controlling initial disturbance.

Because of the great success of the theory in the subsonic case, Lees and Lin[18, 19] extended the theory to compressible flow. Here the chief mechanism of stability is essentially the same as for the incompressible case. The effect of heat transfer was found to be quite marked. Experimental confirmation of these results is not yet available.

Turbulent motion

In spite of intensive study by several teams of research workers, a real understanding of the turbulent motion of fluids still eludes us. The greatest progress has been made in the theory of isotropic turbulence, the simplest theoretical case and one which can be produced experimentally. The typical experimental situation is the flow downstream from a screen or grid of cylindrical wires. At a sufficiently high Reynolds number of the wire, the usual Kármán vortex street breaks up rapidly and a state of isotropic turbulence is obtained which slowly decays. The flow can be described statistically by the root-mean-square velocity fluctuation and a double-correlation function. Suitable lengths derived from the correlation function define various measures of the scale.

Recent progress on the theoretical side describes the statistical-flow field in terms of the spectrum, generalised by Heisenberg[20] from the one-dimensional spectral distribution function introduced by Taylor to a three-dimensional distribution. The randomly-fluctuating space variations of the velocity components at any instant are considered to arise from a superposition of harmonic waves of continuously-variable wave numbers K_x, K_y, K_z, in the directions of the selected reference axes. With suitable assumptions, which are probably valid for the actual turbulent motion, a spectral function can be defined which gives the contribution to the total turbulent energy of waves for which the wave numbers lie within the limits $K<(K_x^2+K_y^2+K_z^2)^{\frac{1}{2}}<K+dK$. Progress along this line has recently been reviewed by von Kármán[21]. The physical picture is that the large-scale eddies arising from flow separation transfer their energy through eddies of successively smaller sizes. Viscosity plays a role only in the smallest eddy motions. Kármán assumes a transfer function for the energy between different wave numbers dependent only on the two wave numbers and the energy density. He then discusses the spectra to be expected in the initial, intermediate, and final stages of decay. To the aeroplane designer of to-day these discussions seem far-removed from his daily problems. They are, however, the initial steps in understanding phenomena which produce his problems.

Progress in understanding turbulent shear flow moves still more slowly. I have reviewed this subject elsewhere[15, 17]. The aeroplane designer is perhaps most interested in the problem of separation of turbulent flow. There are only a few fragments of basic information at present. Recent unpublished work shows that the spectrum of the non-isotropic turbulent motion in a boundary layer is similar to the spectrum of isotropic turbulence. The work described in the references cited shows that the turbulent fluctuations do not change greatly

in magnitude as the flow encounters an adverse pressure gradient and approaches separation. The turbulent shear stress falls in such a region because the correlation between the longitudinal and lateral components decreases. It is interesting to speculate whether the correlation is reduced as a result of the decreasing gradient of the longitudinal velocity in a direction normal to the surface, which in turn results from the adverse longitudinal pressure gradient. Much more theoretical and experimental work is needed. In the meantime the designer must rely on empirical test results.

Supersonic jet mixing

Another typical situation which is adaptable to a joint experimental and theoretical attack with some prospect of improving our understanding of basic principles, is that of mixing of a jet of air with the surrounding still air. Moreover, mixing phenomena in themselves are of great practical interest, and even empirical information is useful. A considerable amount of work has been done on this problem, both experimental and theoretical. Most of the theoretical work on turbulent mixing has been based on the Prandtl mixing-length concept. Most of the experimental work has dealt with the incompressible case for which the density of the jet is the same as that of the surrounding fluid and the velocity is small.

Recently Gooderum, Wood, and Brevoort[22], of the N.A.C.A. Langley Laboratory, studied experimentally the mixing of a supersonic free jet of Mach number 1.6, for which the density of the jet was about one and a half times the density of the ambient air, the high density resulting from adiabatic expansion of the air in the jet from a high-pressure reservoir. The nozzle was of the two-dimensional type, but the exit opening was three inches square.

The measuring tool was an interferometer, an instrument which is finding extensive application in fundamental research in fluid mechanics. The general arrangement and design of the particular instrument of Gooderum, Wood, and Brevoort, is of some interest since the instrument has remained in perfect adjustment for about nine months with no adjustments of any kind during that period, although located on the second floor of a building in which motors, compressors, and other sources of vibration are present and although no temperature control is provided. This phenomenal result is obtained by the symmetrical design illustrated in Fig. 8, and by careful attention to mechanical design. The light source is of the type which was earlier used by Ladenberg and his colleagues at Princeton. Light from a high-voltage magnesium spark is passed through a spectrometer to give a monochomatic source. The duration of the spark is of the order of three microseconds. The mirrors and splitter plates are four inches square.

Figure 9 shows an interferogram at the exit of the nozzle and Fig. 10 a matched set covering the region out to 8½ inches from the nozzle exit. At the nozzle exit (Fig. 9) the boundary layer that has built up along the nozzle wall emerges and maintains its identity for a short distance. At a distance of about two inches, however, its effect appears to be small.

The interferograms give the density variation across the mixing zone. The velocity distributions were calculated on the basis of certain assumptions, *i.e.* (1) that the static pressures in the jet and in the mixing region are the same as the pressure in the ambient air (supported by the weakness of the shock wave in Fig. 9); and (2) that the stagnation temperature in the mixing zone is equal to the room temperature (the stagnation temperature of the jet was always not more than 7°F lower than room temperature). The resulting velocity distribution is shown in Fig. 11. The velocity distributions were similar to each other at the cross sections investigated and affine to the distributions at subsonic speeds. The rate of spread of the mixing region of this supersonic jet is about four-fifths that of a subsonic jet.

Flame propagation in high-velocity gas streams

As a final example of research planned and conducted for the purpose of gaining an understanding of fundamentals, let us consider the problem of flame propagation in high-velocity gas streams, high-velocity in this instance meaning 100 to 400 ft./sec. The work to be mentioned might equally well have been used as an example of exploratory research, since there is little information of a fundamental nature available. The work referred to is that of A. C. Scurlock[23] at the Massachusetts Institute of Technology.

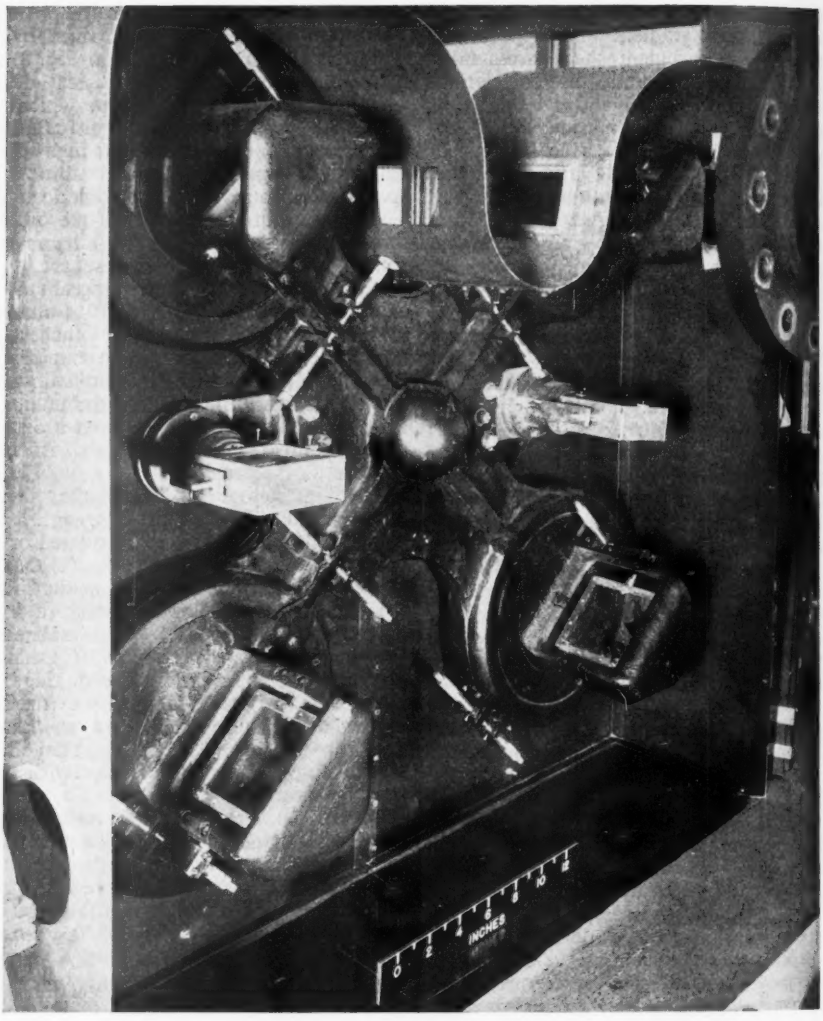


Fig. 8.
Interferometer used by N.A.C.A. Langley Physical Research Division (splitter plates at lower left and upper right; mirrors at upper left and lower right; compensating plates at centre right and left).

The experimental apparatus was constructed so that a homogeneous mixture of air and gaseous fuel (Cambridge city gas or propane) could be introduced into a combustion chamber of rectangular cross-section (1×3 inches), the air-fuel ratio could be varied over a wide range, and combustion chamber entrance velocities from 20 to 350 ft./sec. could be obtained. The intensity of small-scale turbulence could be varied from less than 0.5 per cent. to 8.0 per cent., and its scale from 0.01 to 0.08 inch. Flame stabilisers consisting of single rods, 30° gutters, flat plates, and multiple

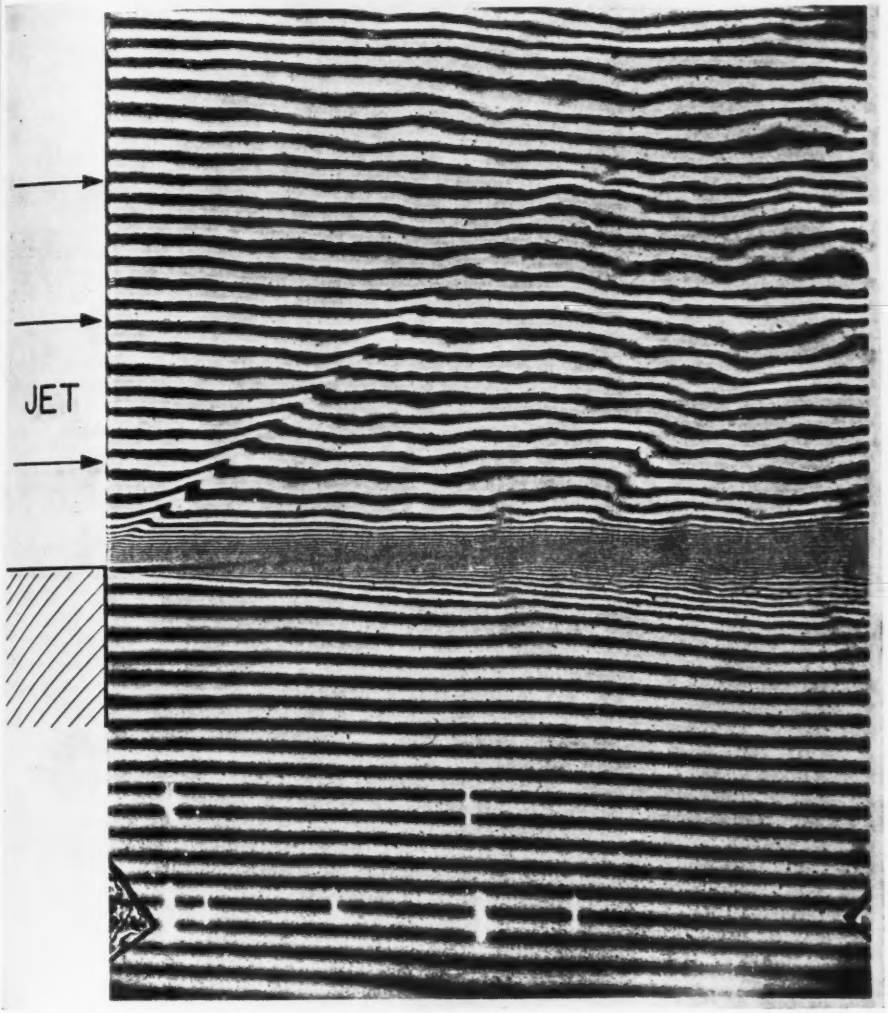


Fig. 9.
Interferogram of supersonic free jet, 0 to 1½ inches from nozzle exit.
(Lower jet boundary near centre of figure, weak shock wave proceeding from end of nozzle at left.)

rods, were used, with dimensions normal to the flow of 0.016 to 0.5 inch. The inlet pressure was approximately atmospheric and the inlet temperature 300° to 340° K.

This study was extraordinarily fruitful in ideas which should be explored further, especially with apparatus of larger scale. This fortunate result is due in large measure to the careful control of the numerous variables, including the elimination of the numerous variables associated with liquid fuel. Such simplification of the experimental situation is a prerequisite to a search for understanding.

Fig. 10.
Composite interferogram of supersonic free jet, 0 to 8½ inches from nozzle exit.

Space will not permit a complete review of this important paper. One of the stimulating ideas is as follows. The added pressure drop when heat is added to a flow by combustion is a well-known phenomenon. Scurlock's experiments show that the combustion process produces burned gases of lower density, which are accelerated more rapidly by a given pressure drop than the unburned gases, giving rise to velocity gradients and turbulence. In most cases this flame-generated turbulence is of far greater importance than either the small-scale turbulence in the approach stream, or the turbulence generated by a flame stabiliser. In fact the classical Kármán vortex trails behind a flame stabiliser usually disappear after combustion takes place.

On the basis of theoretical considerations and a few experiments, Scurlock concluded that rough burning is due to random fluctuations of the fraction of fuel burned at any cross-section, these causing fluctuations in the pressure drop which influence the mass flow. Burning is roughest when the fraction is nearly unity. When resonance or flutter occurs, the period of vibration is the resonant frequency of some portion of the system.

Some unpublished work of the N.A.C.A. Lewis Laboratory suggests that we should also consider most combustion processes as equivalent to a non-uniform addition of heat over the cross-section, giving rise to transitory localised regions of greater or less pressure drop, which react on the approaching flow to generate non-uniform approach velocities.

SEARCH FOR AND EVALUATION OF TEST METHODS AND PROCEDURES

In all aspects of aeronautical research and development there is constant need for the invention and evaluation of new test methods and procedures and for the critical examination of methods and procedures in use for the more routine investigations. The designer wishes to know whether the research equipment yields numbers which are applicable to his aeroplane in flight. The question "Does this wind tunnel give results applicable to the full-scale aeroplane?" is disarmingly simple, just as simple as the question asked every day in the camera shop, "Will this camera give pictures of my children true to life?" The wind tunnel, like the camera, is only a tool. If it is a good tool, designed for the particular purpose, and is intelligently handled, it will produce the desired result. No one tool will accomplish all purposes, even in the most skilled hands. It is not possible to take any single model, place it in any single wind

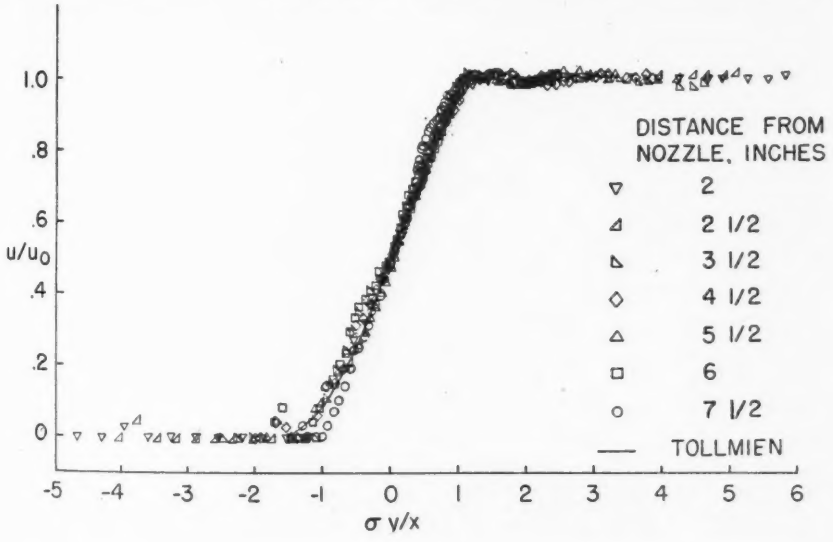


Fig. 11.
Variation of velocity ratio through mixing region (scale factor $\sigma = 15$ for supersonic jet compared to 11.8 to 12 for subsonic jets).

tunnel, and measure everything the designer would like to know about the behaviour of his full-scale aeroplane. Test methods and procedures are themselves constant objects of research and, as they are expanded in number and variety, more and more information can be obtained for designers without hazard to life or to an expensive prototype. Although there are few groups permanently and continuously engaged on this research goal, this activity is a most important one.

PROCEDURES FOR HIGH SUBSONIC AND TRANSONIC SPEEDS

During the past decade as aeroplane speeds have steadily increased it has become necessary for research workers to develop methods for determining the lift, drag, and stability, of configuration at speeds approaching and exceeding the speed of sound. Only the barest outline of these developments can be presented here. The basic tool, the wind tunnel, suffers from the limitations produced by the phenomenon of choking; when the speed of sound is reached at the smallest cross-section, the mass flow cannot be further increased. In the older wind tunnels, the smallest cross-section was at the model since it blocked a part of the area. The quantitative relations are such that a model which blocks only five-tenths per cent. of the area limits the test speed to less than 0.92 the speed of sound. The first

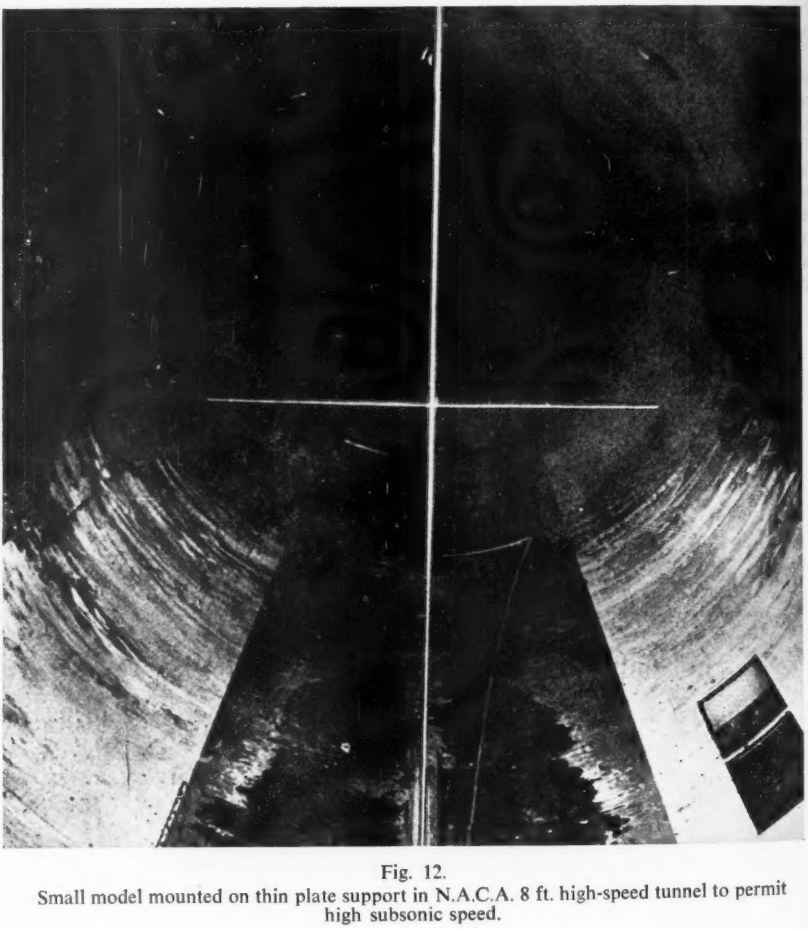


Fig. 12.
Small model mounted on thin plate support in N.A.C.A. 8 ft. high-speed tunnel to permit high subsonic speed.

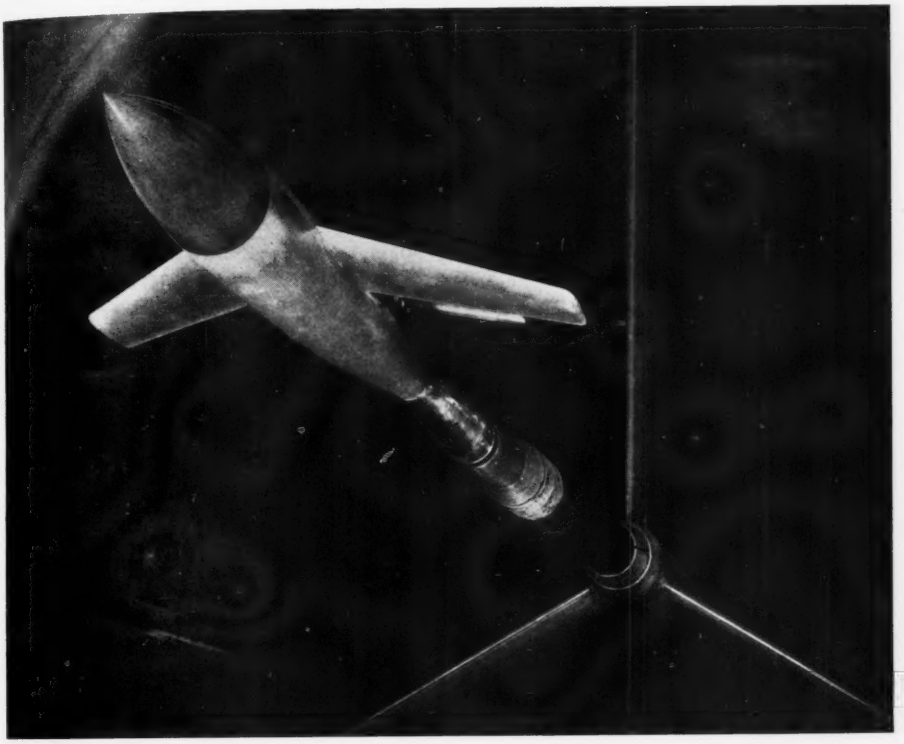


Fig. 13.
Aeroplane model on sting support in N.A.C.A. 8 ft. high-speed wind tunnel.

approach was to limit greatly the model size, as indicated in Fig. 12, which shows a downstream view of a model of about 32 inches span in the N.A.C.A. 8 foot high-speed wind tunnel. Measurements were made by wake survey or by pressure distribution.

The next step was the development of sting supports to mount a small model from the tail end, and later the incorporation of an aerodynamic balance of the electrical strain gauge type within the model. It is found desirable to introduce a liner in the wind tunnel so that choking occurs first at the model, rather than at the support strut; otherwise the test speed would be limited to the lower value fixed by the blocking at the support strut. A close-up view of an aeroplane model on a sting-support in the N.A.C.A. 8 foot high-speed tunnel is shown in Fig. 13.

The expedient of miniature models has enabled measurements to be made on some models at speeds up to about 95 per cent. of the speed of sound. During the same period in which these developments occurred, supersonic wind tunnels have also been under continuous development. The first ones could operate only at a single fixed speed, or at a few discreet speeds obtained by alternate nozzle blocks. Flexible nozzles enable a continuous variation of speed, but there remains a lower limit of supersonic speed below which the results are unreliable because shock waves set up at the nose of the model are reflected from the wind tunnel walls at such a near-normal angle as to strike the model, disturbing the flow. The wind tunnel thus has a blind spot in the region near the speed of sound, the transonic region.

The first method considered to bridge the gap was the use of heavily-weighted models dropped from an aircraft at high altitude, as shown in Fig. 14. This programme was planned jointly with your Aeronautical

Research Council, and we have been able to secure considerable data on drag by this means.

R. R. Gilruth developed the wing-flow method which he described at the Joint R.Ae.S.-I.Ae.S. Conference in 1947.* This method depends on the fact that there is a region of supersonic speed over a part of the upper surface of the wing of a fighter aeroplane diving at speeds of about 0.7 the speed of sound Over a limited area the speed is approximately uniform, and its value may be varied continuously through the speed of sound by diving the aeroplane at increasing speeds. Fig. 15 shows a mock-up of the wing-flow apparatus, a small aerodynamic balance built within the wing. This method has given very useful data, although the Reynolds number is low. We still find the method useful, although I think that in time, it will be supplanted by other methods.

The same principle has been applied almost simultaneously by the Lockheed Aircraft Company (in the Co-operative Wind Tunnel at the California Institute of Technology) and the N.A.C.A. to wind tunnels by installing a suitably-shaped bump on the wall of a high-speed wind tunnel. Fig. 16 shows a model of a 51° swept-back wing on a bump in the N.A.C.A. Langley 7 x 10 foot wind tunnel for investigations of lateral control at transonic speeds.

Perhaps the most useful method of all is the rocket-propelled ground-launched

* GILRUTH, R. R. Résumé and Analysis of N.A.C.A. Wing-Flow Tests. *Aeronautical Conference* 1947. Published by The Royal Aeronautical Society, London, 1948.

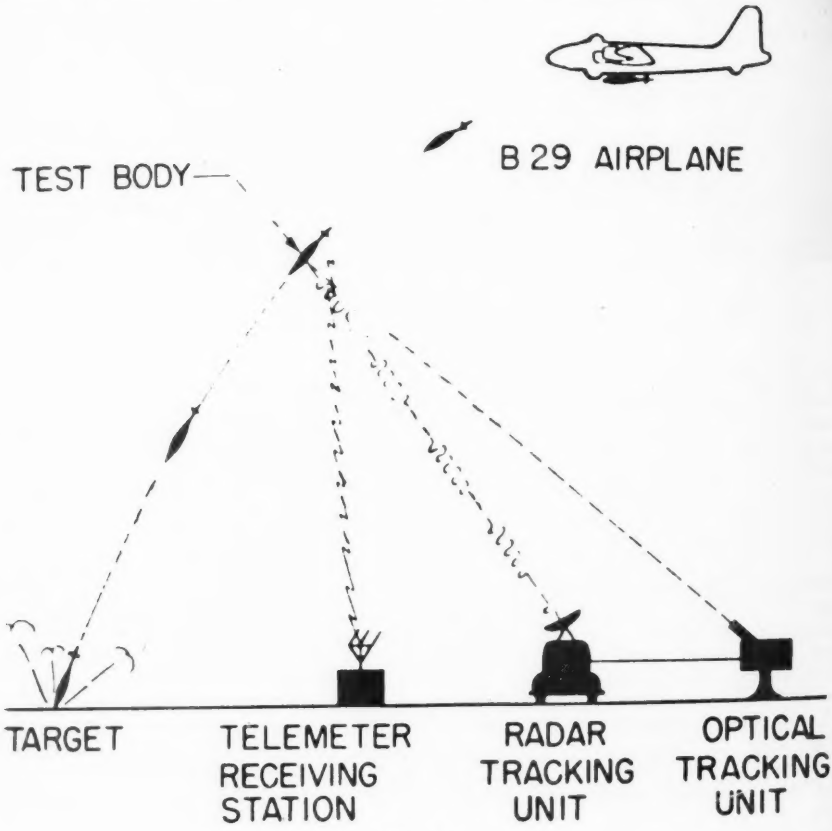


Fig. 14.
Schematic sketch illustrating drop-test procedure to obtain data at transonic speed.

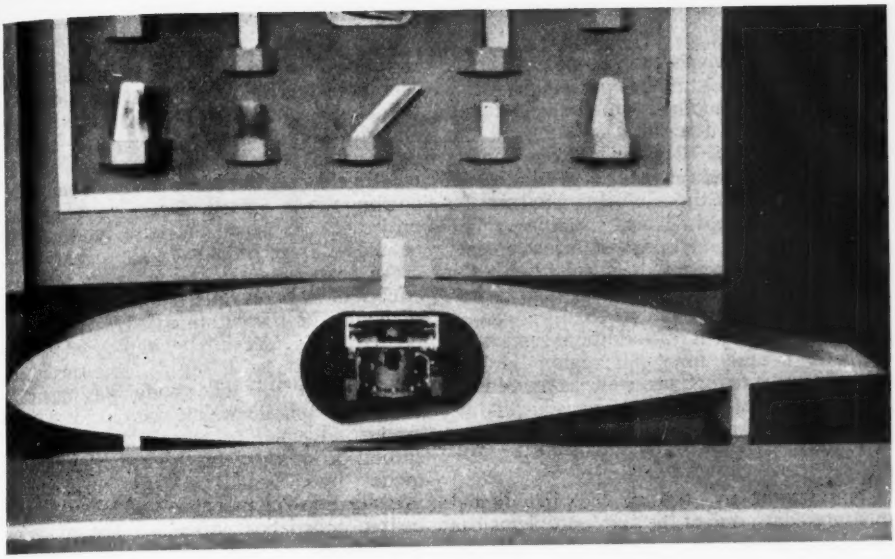


Fig. 15.
Mock-up of wing-flow apparatus.

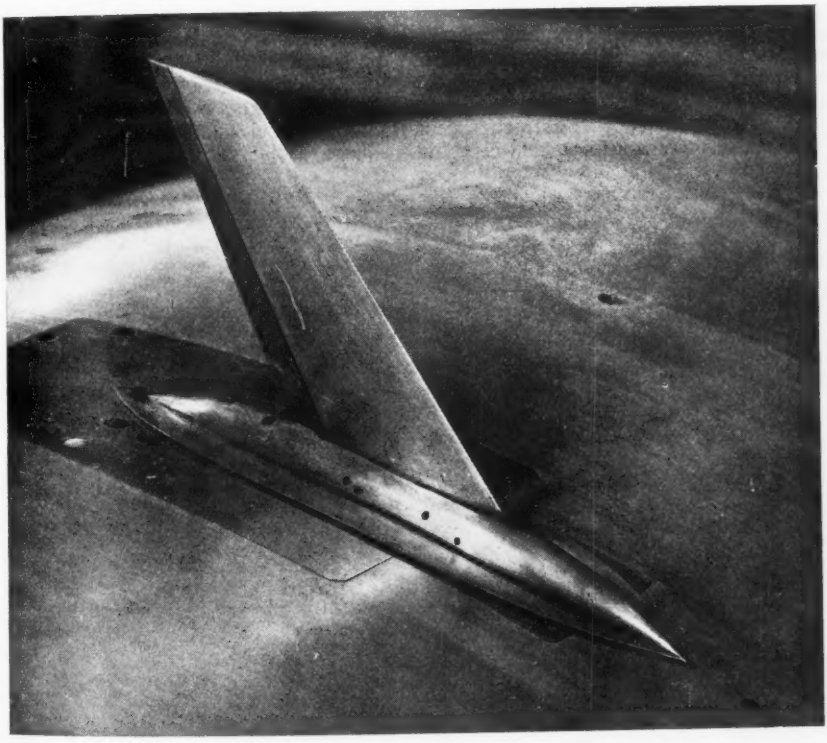


Fig. 16.
Model of swept-back wing on bump in N.A.C.A. Langley 7 x 10 ft. wind tunnel.

research model which enables measurements at high Reynolds number and high Mach number. This method and some of the results will be described to you at the forthcoming joint R.Ae.S.-I.Ae.S. Conference in New York in May 1949. Fig. 17 shows one of the models being fired at the N.A.C.A. Wallops Island station. The models carry various measuring instruments whose indications are telemetered to the ground. Radar methods are used for speed and deceleration measurements.

The development of additional research methods in the transonic region is still actively in progress, as well as continued improvement of the ones already available.

Evaluation of Drag Measurements—The Support Problem

Throughout the history of wind tunnel measurements, one of the many problems has been the evaluation of the drag of the support and the interference effect of the presence of the support on the drag of the model. The ideal method of restraining the model would be one in which no material support was required; but this, unfortunately, is not practical except in a very few cases, such as spin tests in a vertical wind tunnel. The tail spindle, which has become the common method of support at high speeds for the reasons previously stated, is about as ideal a method as can be desired from the standpoint of minimising interference with the flow around the model, except at the extreme tail. Moreover, its drag can be made relatively small by the use of a suitable windshield. Nevertheless there are numerous configurations, particularly missiles and projectiles, in which the base pressure contributes a large fraction of the overall drag.

An experimental investigation of the effects of support interference on the drag of bodies of revolution at a Mach number of 1.5 was recently completed in the N.A.C.A. Ames 1 by 3 foot supersonic wind tunnel[24]. The body was mounted on a tail spindle which was enclosed in a shroud attached to the balance cap, the shroud being separated from the base of the model by a small gap. The complete investigation included a model with six-calibre ogival boat-tailing. The effects of roughening the nose to produce a turbulent boundary layer were studied and the interference effects of a tail spindle were determined by using alternate support systems. Schlieren photographs were taken of the flow about the various configurations.

Figure 18 shows the effect on the base drag coefficient of varying the ratio of support length to body diameter, for a smooth model with cylindrical afterbody and square base. As the support length was

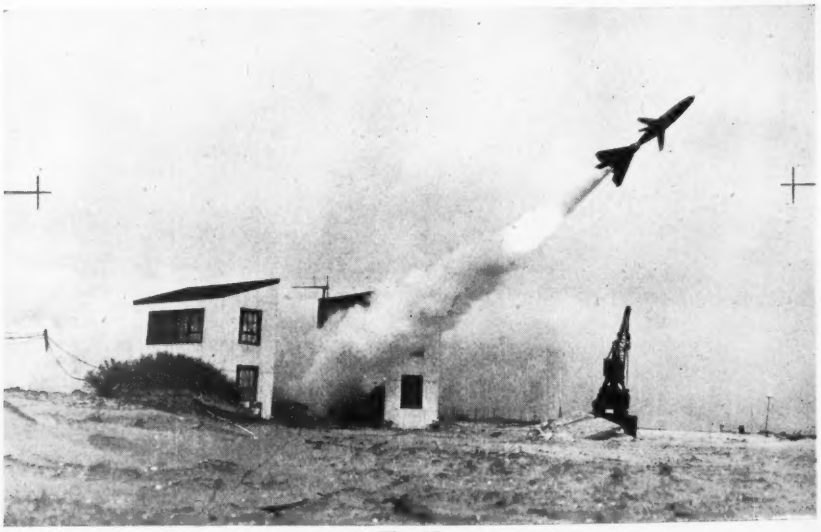


Fig. 17.
A rocket-propelled research model fired at N.A.C.A. Wallops Island Station.

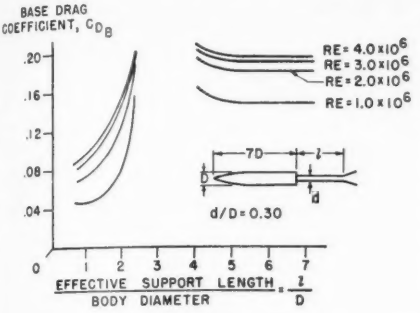


Fig. 18.

Variation of the base drag coefficient with support length at a Mach number of 1.5 (support diameter = 0.3 body diameter).

increased from one to 2.4 body diameters, the convergence of the wake was observed to increase and the base drag to increase. In the region from 2.4 to 4.1 body diameters, in which no tests were conducted, the shock-wave configuration changes from one in which the trailing shock wave and the shock wave from the beginning of the balance cap coincide to one in which the two shock waves occur separately.

Figure 19 shows that the base drag increases to a maximum as the support diameter is increased. It was observed that this increase was accompanied by greater convergence of the wake and forward movement of the trailing shock wave. The base drag increases with Reynolds number within the range tested. As the support diameter approaches the body diameter, the base drag decreases sharply as the wake ceases to converge.

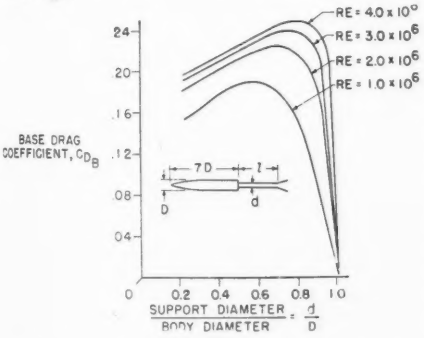


Fig. 19.

Variation of the base drag coefficient with support diameter at a Mach number of 1.5 (support length = 4.1 to 5.4 body diameters).

The fore drag of this model was not affected by the presence of the rear support. The interference studies showed that the curves of Fig. 19 could not be linearly extrapolated to zero support diameter. Results most free from interference were obtained with a support diameter of 0.35 body diameter and a support length of 4.1 body diameters. The investigation showed that the effects of boat-tailing, surface roughness, and Reynolds number must be considered in designing the supports and evaluating the interference.

This investigation gives some idea of the type of research needed to obtain meaningful drag measurements for certain types of models.

Techniques of Measurement on Rotating Turbine Blades

Examples of the constant necessity for the development of new techniques and research on problems of measurement can be found in any field of aeronautical research. In the gas turbine field we might cite the high-temperature strain gauge[25] which has permitted the measurement of vibrating stresses in operating gas turbines. Fig. 20 shows measurements made with a ceramic strain gauge mounted on a blade subjected to normal operating conditions in a jet propulsion engine, taken as part of an investigation of the effect of loose mounting of turbine blades. The tip movement of the blade under static conditions was 1/32 inch. Neverthless, many points of vibration were observed, with stress amplitudes as high in most cases as those of a similar blade tightly mounted. It must be concluded that the mere presence of looseness in the mount is no fundamental insurance against blade vibration.

To assist in the interpretation of stress data, and to evaluate materials as to their ability to withstand the imposed stresses, it is important to know the operating temperatures. Direct measurement of temperature of rotating parts by means of thermocouples has been found practicable, provided that suitable slip rings and brushes are used to transmit to stationary recording equipment the voltages generated at the thermocouple junctions. The data shown in Fig. 21 were obtained from thermocouples mounted near the leading edge of a turbine blade, which were connected to recording equipment by copper brushes resting on copper slip rings.

The temperature distribution along the length of the blade is shown for the rated speed and for two speeds below rated speed. Considerable temperature gradient along the blade is present, which indicates a need for improvement in uniformity of burning in combustion chambers. Knowledge of the temperatures allows the prediction of blade life, determination of permissible vibration stress, and the assessment of the suitability of any specific blade material to withstand the operating stresses.

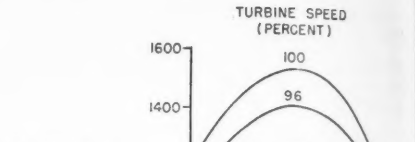


Fig. 21.
Turbine-blade operating temperatures.

THE SCALE-EFFECT PROBLEM

Reference has already been made to the scale-effect problem, which is a part of the more general problem of the comparison of wind tunnel and free-flight data. The general problem includes so many variables that no brief treatment is possible. One must examine in the general case such matters as the exactness of geometrical similarity of model and full-scale aeroplane, including the aeroelastic effects on each, effects of power, precision of measurements, nature of corrections to both wind tunnel and flight data, and so on.

The problem of scale effect should be studied at every opportunity. The N.A.C.A. had occasion to make wind tunnel measurements of a 1/78-scale model and a 1/3-scale model of a certain aeroplane, and flight measurements on the actual aeroplane. Figs. 22 and 23 show the drag and lift coefficients respectively, plotted against Mach number. It will be observed that the drag coefficient begins to rise earlier for the small-scale model, and the rate of drag-rise past the force break is appreciably less than for the large-scale models. The lift coefficient shows a similar early force break for the smallest model and the magnitude of the lift coefficient at a given angle of attack is smallest for the smallest model. In other words, the small model, for which the Reynolds number was 270,000 to 370,000, gives a pessimistic picture of the compressibility effects.

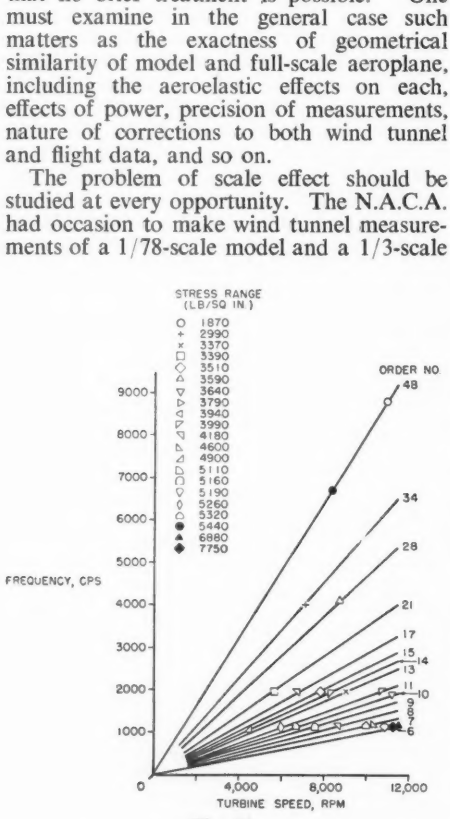


Fig. 20.
Critical-speed diagram and measured stresses in loosely-mounted turbine blade.

Other tests show that detailed differences depend on the state of the boundary layer flows, which can be modified at high subsonic speeds by surface roughness and wind tunnel turbulence as at lower speeds. If one knew how and where to control transition points to agree with those on the full-scale aircraft, the quality of aerodynamic measurements on models would be improved.

The accumulated experience to date shows that for some aerodynamic measurements on nearly all types of models, and especially for certain types of models there are appreciable effects of Reynolds number even at high subsonic and supersonic Mach numbers. The qualitative effects may often be explained in terms of the factors controlling transition of the flow in the boundary layer from laminar to turbulent and the consequent effects on separation and boundary-layer shock wave interaction. Much work remains to be done, but enough has been

done to show that the problem cannot be solved by a single research project for making comparisons between model and flight. The comparisons must be a continuing objective of aeronautical research.

SYSTEMATIC SURVEYS

The exploration of new fields and the search for understanding proceed at a rather slow pace, since discovery of new phenomena, the creation of new concepts, and the gaining of insight, require the talents of specially gifted persons who appear in the population in limited numbers. By contrast, the systematic survey of phenomena in a limited field can be conducted on any desired scale by the organisation of teams of workers, with an almost certain guarantee of results of great value to designers. If these surveys are planned in close co-operation with designers, with an eye to the general problems facing them in the near future, the results become the basis for greatly accelerating advances in the performance of aircraft. The activity is a research activity, producing systematic, quantitative design data, but also yielding improved and more rational approaches to specific design problems. This type of research is one of the most important functions of the National Advisory Committee for Aeronautics. The N.A.C.A. seeks to anticipate, in so far as possible, the needs of designers, to promote exploratory research and basic research, and to conduct applied research directed toward the general goals suggested by the needs of the designers. While available theoretical methods are utilised to the greatest extent possible, and the development and improvement of theory is a hoped-for result, the immediate aim is not development of theory, but systematic survey of the field.

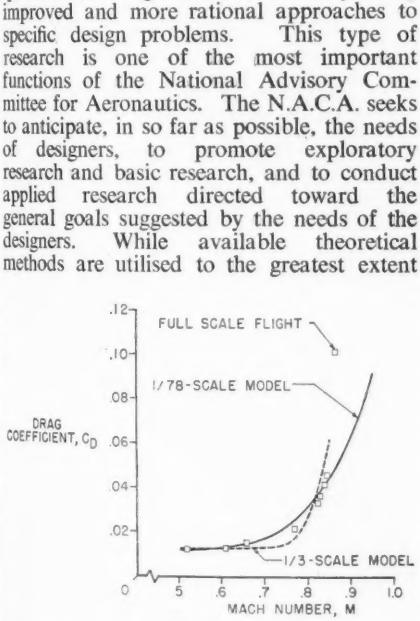


Fig. 22.
Comparison of variation of drag coefficient with Mach number for 1/78-scale model, 1/3-scale model, and full-scale aeroplane.

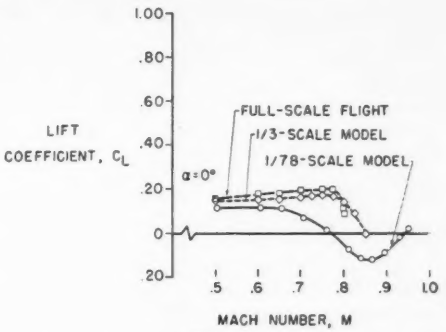


Fig. 23.
Comparison of variation of lift coefficient with Mach number for 1/78-scale model, 1/3-scale model, and full-scale aeroplane ($\alpha=0°$).

INLETS

A good illustration of this type of research is that now under way on air inlets. Although the proper design of air inlets for aircraft power plants has always been important, the attention given to this phase of aerodynamics has increased greatly during the past few years. This increased significance is due to a change in the method of propulsion and to the rapid increase in maximum aeroplane speed.

Although the reciprocating engine requires considerable cooling air, only the air necessary for combustion passes through the engine, and the propulsive force results from the action of an engine-driven propeller. By contrast, the jet engine requires large quantities of air, which become a part of the aero-thermodynamic cycle resulting in a discharge of the air at high velocity to produce propulsive force by jet reaction. Combustion is satisfactory and efficient only at comparatively low air speeds. Hence the air taken in at the air inlet must be decelerated. If this deceleration is done efficiently, the kinetic energy will be converted to pressure yielding an increase in the compression ratio of the engine with no increase in the compression power required. An aeroplane flying at 500 miles an hour at 40,000 feet compresses the inlet air through a compression ratio of 1.5. At 1,200 miles an hour the maximum available ram

compression ratio is about six, and at 2,000 miles an hour, about 36.

The performance of the aircraft depends not only on the available engine thrust, but also on the drag of the aeroplane. There is no point in using an air inlet which gives efficient energy recovery and increased thrust, if at the same time the inlet increases the external drag by an equal or greater amount. This is but one of the many compromises facing the designer.

The experimental study of any general type of inlet will soon show that satisfactory operation is obtained only when the ratio of inlet velocity to free-stream velocity is restricted to lie within certain limits. This, together with the required quantity of air, fixes the size of the inlet which may affect the external drag. Further, the performance of any particular inlet or type of inlet will depend greatly on the speed of the approach stream, *i.e.* whether it lies in the subsonic, transonic, or supersonic range.

Finally, the designer may be limited as to location of the inlet. Whereas from the point of view of the aerodynamicist the inlet at the nose of the fuselage may give the optimum performance, the electronics designer may wish to place a radar scanner in the nose, or the armament designer may wish to install guns in the nose. The designer thus needs to know more than the optimum aerodynamic design and location of inlet. He wishes to know what penalties will be suffered at other locations, and what design is optimum at other locations with due regard to the air speed and size required for a given power plant. In other words he wishes systematic surveys of the performance of inlets at all possible locations, together with detailed studies of the effect of various details of design on the performance over ranges of variation to cover design details he might wish to use. Fig. 24 shows some of the types of inlets which are of present interest to designers.

E. A. Mossmann, of the Ames Aeronautical Laboratory, has prepared for this lecture a brief account of some of the many facets of this problem.

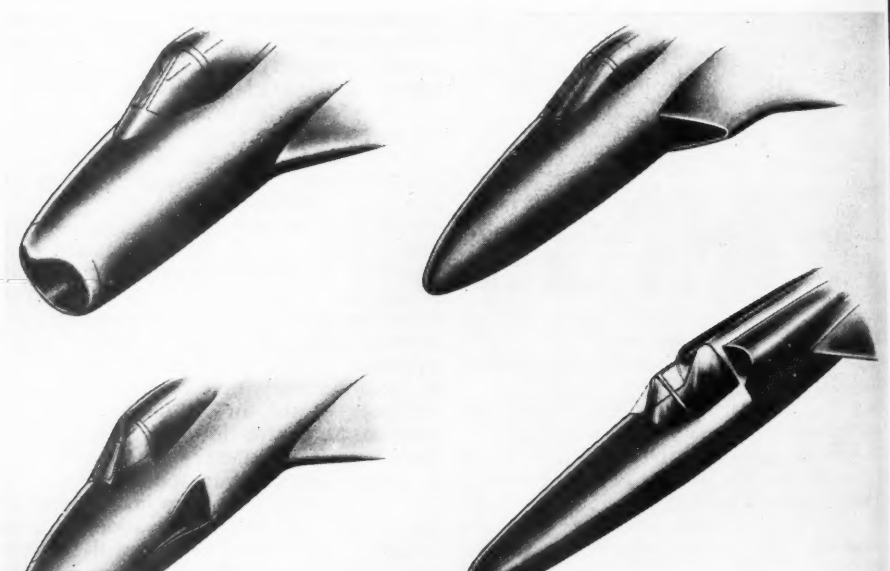


Fig. 24.
Various types of air inlets.

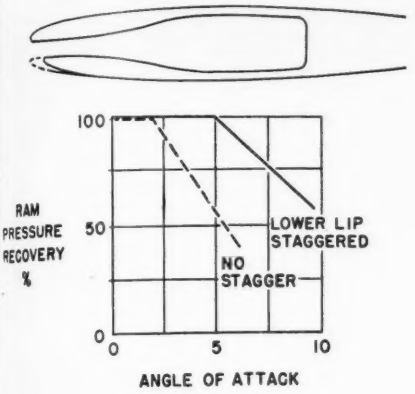


Fig. 25.

Effect of stagger on ram pressure recovery of wing leading-edge inlet.

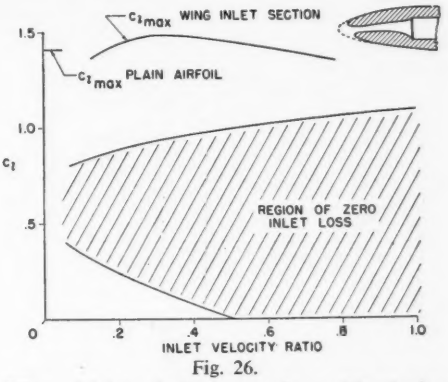


Fig. 26.

Effect of inlet velocity on maximum lift of wing with leading-edge inlet.

Subsonic inlets

It is convenient to classify subsonic inlets into two general divisions; the first consisting of those utilising free-stream air only, further classified as nose inlets, wing-leading-edge inlets, and projecting external scoops; the second consisting of inlets located in a region of considerable boundary layer, further classified as scoops, expanded wing-fillet inlets, and submerged inlets.

Nose inlets have been used extensively and are particularly adaptable to certain engine installations. Most familiar, perhaps, are their use as cowlings with reciprocating engines to admit efficiently the cooling and carburettor air, while reducing the external drag of the engine installation. Research on this phase of the air-induction problem has evolved the N.A.C.A. C, D, and E cowlings, which are suitable for turbo-propeller and reciprocating-engine nacelle designs, and the N.A.C.A. 1-series nose inlets[26] used extensively as contours for turbo-jet nacelles. Other N.A.C.A. research has been performed on multiple turbo-jet nacelle designs in connection with an Air Force high-speed bomber competition. These nacelle lines are noticeable on the B-45 and the B-46.

The general aerodynamical problem of nose-inlet (or nacelle) design is to minimise the drag due to wing-nacelle interference, and to contour properly the duct lip so that good pressure recovery is obtained over a large range of angles of attack and inlet-velocity ratios. The lip and body contours that satisfy these requirements are further limited to those that avoid a premature drag rise during high-speed flight.

The problems involved in the design of wing leading-edge inlets are analogous to those encountered in the development of aerofoils. Such an inlet should be designed to give high ram-pressure recoveries and to cause no deterioration of the lift and drag characteristics of the wing itself. These conflicting requirements involve compromises of the geometrical design parameters. As an example, such features as large nose radii and thick lip sections help to prevent separation of the flow over the duct lips. Small nose radii and thin lip sections, however, are favourable for high critical speed. The effects of angle of attack on wing leading-edge inlets can be more severe than on any other type of inlet. Lower-lip stagger will extend the angle-of-attack range for satisfactory pressure-recovery characteristics (see Fig. 25). Too much stagger will cause a loss in maximum lift and result in inferior performance during take-off and landing.

The degree to which the conflicting requirements of high maximum lift and low ram losses has been met for a moderately thick wing is shown in Fig. 26. The maximum lift coefficient for the inlet section is substantially the same as for the plain aerofoil over a wide range of inlet velocity ratios. Zero inlet loss, or full ram-pressure recovery, at the inlet is obtained over a range of lift coefficients and inlet-velocity ratios sufficiently wide to permit the inlet to be designed for efficient operation under all conditions of flight. Such inlets still

Fig. 27.
Expanded wing-fillet inlet with boundary layer removal scoop.

require individual development. More research is needed to obtain the systematic data required to permit successful design.

The wing leading-edge inlet is applicable to many engine installations for admitting cooling and carburettor air. Its use with small and medium jet-powered aeroplanes would seem to be limited because of the necessity for large openings and the tendency toward thinner wing sections. For large aeroplanes with the jet engine almost completely submerged in the wing structure, the wing leading-edge inlet may prove to be the most satisfactory solution.

External scoops which project far enough from the fuselage to be outside the influence of the boundary layer (P-51 cooling scoop) have the advantage of eliminating much of the internal ducting. Usually, however, the drag of this type of inlet is appreciable.

Inlets situated in a region of considerable boundary layer include the external scoop, the expanded wing-fillet type, and the submerged inlet.

With an external scoop which includes the boundary layer, it is usually necessary to provide a boundary layer bleed duct in order to secure successful operation[27] (see P-80 inlets). The energy expenditure in removing this boundary layer air is chargeable against the inlet. The comments previously made on the external-scoop inlet apply for this case also.

The expanding wing-fillet air intake incorporates many design features of the previously mentioned wing leading-edge and external scoop inlets. Usually they are used with intercepter aeroplanes, in which case the jet engine, or engines, are either in the fuselage or actually in the expanded wing-fuselage fillet. The usual problems associated with fuselage boundary layer removal are encountered, and various means of circumventing this difficulty have been used. Some British and American aeroplanes using this inlet design have a slight bump next to the fuselage in front of the inlet, which is apparently effective in diverting the boundary layer away from the entrance. Other aeroplanes (Fig. 27) utilise a boundary layer removal scoop. Since the inlet is in the flow field of the fuselage, it is

less critical to changes in angle of attack and inlet-velocity ratio than the wing leading-edge type. The principal disadvantages seem to be structural complexity and a somewhat indeterminate drag penalty.

The submerged inlet is the consequence of an attempt to meet the many conflicting requirements posed by the placement of a jet engine in the aft portion of a fuselage. The goal has been to obtain a low-drag inlet combining the high pressure recovery of the nose inlet with the short internal ducting of the external scoop. Two forms of the same basic inlet have evolved. One utilises a straight, parallel ramp leading to the inlet. The other type, a result of N.A.C.A. research, has a curved, divergent ramp leading to the inlet. A comparison of the pressure recovery for divergent and parallel-wall inlets (Fig. 28) indicates that a considerable increase, both at the entrance and at the compressor, results at low mass-flow ratios from the use of divergence.

The increase in the magnitude of the pressure recovery for the divergent-wall inlet over that obtainable with the parallel-wall inlet can be attributed to the difference in the factors governing the boundary layer growth along the ramp. A comparison of the ramp boundary layers for the two inlets (in terms of ram-pressure loss) is shown in Fig. 29. The rapid growth of the parallel-wall ramp boundary layer, as indicated by the momentum thickness, may be visualised from Fig. 30, and may be compared on the same figure with that for the divergent-wall inlet. A boundary layer removal scoop is required for successful operation of the parallel-wall inlet, but none is needed for the divergent-wall inlet, unless it is located in a relatively thick boundary layer.

The thick boundary layer accounts for almost all of the pressure losses with a parallel-wall inlet. However, the thin boundary layer along the ramp is a small portion of the pressure losses at the entrance of an N.A.C.A. divergent-wall inlet. Localised pressure losses occur in two symmetrical regions as shown on Fig. 31. A picturisation of the mixing process which is thought to originate these losses is presented in the same figure.

It has already been mentioned that the divergent-wall inlet gives its optimum pressure recovery at the relatively low inlet-velocity ratio of 0.5. This is a considerable

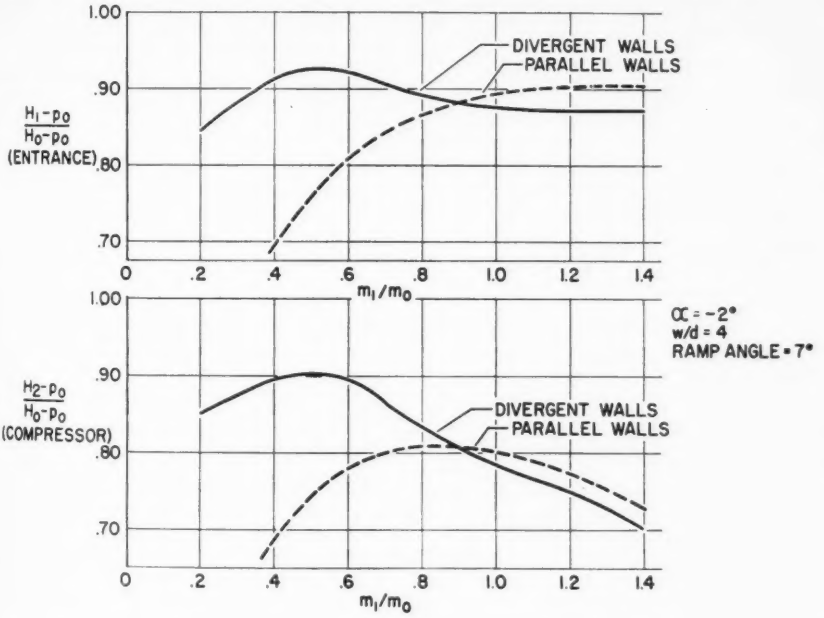


Fig. 28.
Pressure recovery for divergent and parallel-wall submerged inlets.

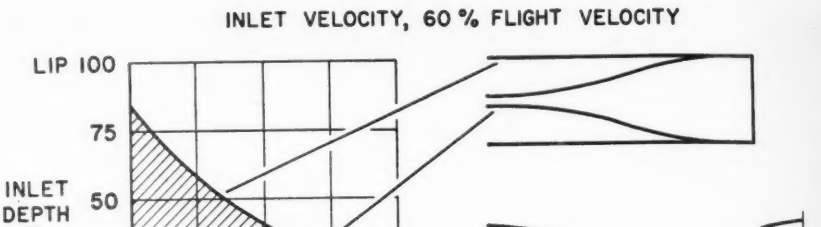


Fig. 29.
Ram pressure loss at varying heights for divergent and parallel-wall submerged inlets.

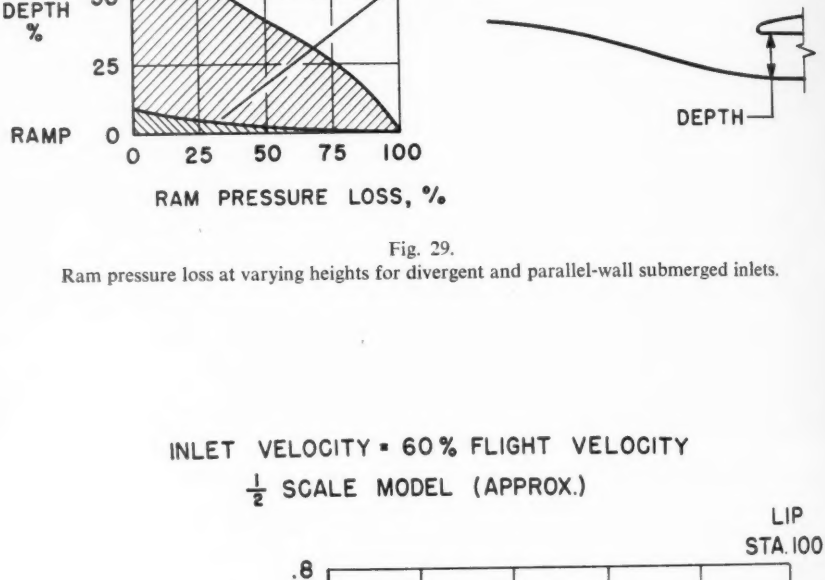


Fig. 30.
Boundary-layer momentum thickness along ramp for divergent and parallel-wall submerged inlets.

disadvantage for application to large power plants in relatively small fuselages. The area required to supply a given amount of air is greater than for the parallel-wall inlet. Moreover, complete data are not available on the drag, although the drag of a properly designed submerged inlet should be relatively small. Much additional research is required to meet the needs of designers.

From the preceding discussion of the various types of inlets being used on subsonic aeroplanes, it may be seen that certain types of inlets are particularly suited for a particular air-induction-system design. However, no one inlet is a solution to be used on all types of aeroplanes, and the ultimate selection will depend on a study of the factors involved.

Supersonic inlets

Up to the present time, it has not been possible to burn fuel at supersonic velocities and the intake air of a supersonic missile or aeroplane must be decelerated through the speed of sound to a velocity low enough to sustain reasonably efficient combustion. High pressure recovery in the combustion chamber is not only a prerequisite for good thermodynamic efficiency, but it is also necessary, at high Mach numbers, to keep the body size to a minimum.

Research groups have expended a considerable amount of effort on the problem of attaining a high pressure recovery at supersonic speeds and, in general, two methods have been suggested. In one, the stream is first decelerated in a converging channel to a low supersonic velocity; it then enters a throat or section of minimum area, where compression to a high subsonic velocity occurs through a normal shock wave. The speed is then further reduced in a subsonic diffuser. The other method employs oblique shock waves and the compression that occurs along the surface of a cone to produce a low supersonic Mach number prior to the normal shock wave in the throat. With the first scheme, the compression of the intake air takes place entirely within the internal-duct system, while in the second a large part of the compression is external. Both schemes attempted to approach the isentropic flow process by keeping the pressure rise across the oblique shock wave to a minimum, and to reduce the Mach number at which the final normal shock wave occurs.

The convergent-divergent supersonic inlet has the advantage of a low theoretical external drag at the design Mach number and mass-flow ratio. It has the disadvantage of a limited operating range for maximum efficiency. If the flight velocity or mass-flow ratio is reduced from the values corresponding to maximum efficiency, unstable operation results.

To stabilise the normal shock wave and to improve the performance of the convergent-divergent inlet, perforations in the walls of the convergent section have been found to be effective. This alteration to the convergent-divergent intake makes its use much more attractive, provided that the mechanical difficulties of opening and closing the perforations can be overcome. The external drag with the perforations open might be excessive.

The conical-shock inlet is efficient over a large range of operating conditions and normally has a higher maximum pressure recovery than the convergent-divergent intake. The conical-shock inlet, or as it is sometimes called, the oblique-shock inlet, has evolved in several basically similar forms. Of these forms, the single oblique-shock type differs from the multiple oblique-shock type and from the continuous-compression type in that a lower pressure recovery is compensated by a reduction in external wave drag, at the design flight Mach number.

By nature of their design, the entrances to the convergent-divergent and to the conical-shock inlets would probably be placed in the nose of a missile or aeroplane. Inlets so located require a great deal of internal ducting to transport the air to the engines located on the rear. This limits the

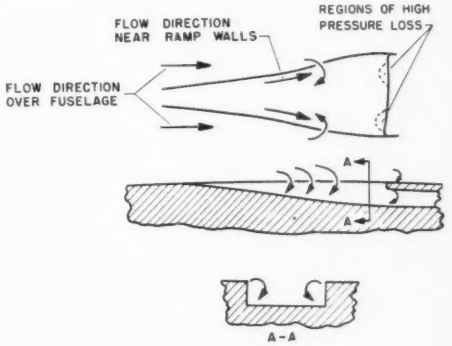


Fig. 31.
Regions of high pressure loss and flow directions for divergent-wall submerged inlet.

useful volume of the fuselage and may increase the pressure losses in the ducts.

The scoop-type induction system alleviates this difficulty by locating the scoops aft on the fuselage near the engines. This inlet utilises oblique and normal shock waves to decelerate the air stream in a manner similar to the conical-shock diffuser. As at subsonic speeds, a boundary layer builds up along the forebody ahead of the inlets and part of the available ram pressure is dissipated due to friction in this layer.

This discussion of the single aerodynamic problem of inlet design shows the ramifications of the attempt to provide systematic surveys to meet the needs of designers for basic data.

Effect of fuel properties on the performance of the turbine engine combustor

As a second example of the systematic survey field, I shall review briefly the results of a programme reported in some detail in a paper with the title given above, which was presented by L. C. Gibbons and E. R. Jonash, of the N.A.C.A. Lewis Laboratory, at the 1948 annual meeting of the American Society of Mechanical Engineers. Early models of turbo-jet engines have been designed to use either high-performance aviation gasoline or a kerosene-type fuel. As turbo jets are put into service in increased numbers, it seems desirable to give further consideration to the most suitable fuel. It is undesirable to burn large quantities of aviation gasoline in engines that can effectively use a less highly refined product, but the present kerosene-type fuel is not available in sufficient quantity to insure a supply for large numbers of aircraft. It was decided to survey the combustion characteristics of the components that would be present in a fuel of wide availability.

The performance parameters of interest to the engine designer are the combustion

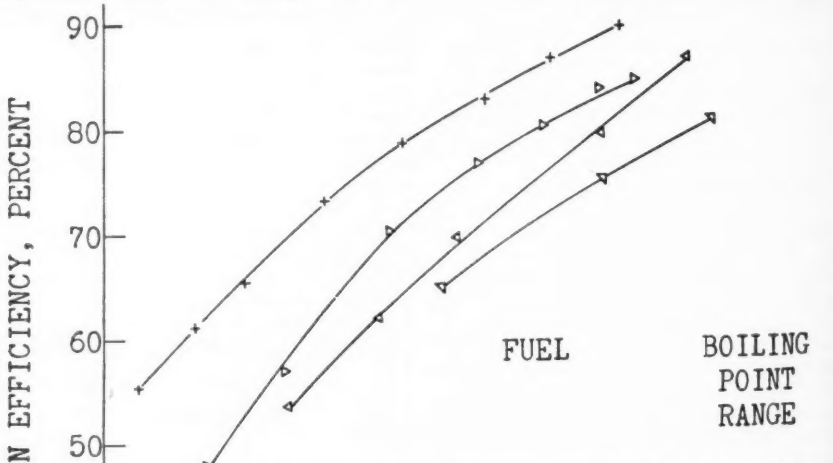


Fig. 32.

Variation of combustion efficiency with mean-temperature rise through tubular combustor for different fuels. (Altitude 45,000 feet, 76% rated speed.)

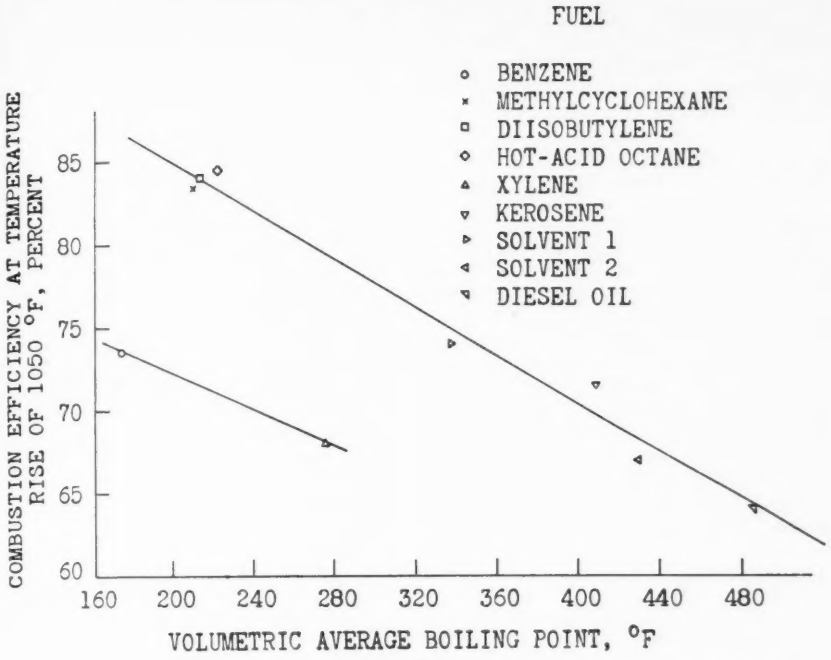


Fig. 33.

Effect of volumetric average boiling point of fuels on combustion efficiency. (Mean-temperature rise 1050°F., altitude 45,000 feet, 76% rated speed.)

efficiency, altitude operational limits, and carbon formation. The resulting values of these parameters depend on the combustor design and conditions of operation, as well as on the fuel. It is therefore necessary to determine the influence of the combustor variables on the relative performance of various fuels, and conversely, to determine the influence of fuel volatility and molecular structure when the combustor variables are held constant.

A study of the effects of inlet-air pressure, inlet-air temperature, and inlet-air velocity, on the combustion of aviation gasoline and diesel oil showed that the optimum inlet velocity for one fuel may not be the optimum for another, and that under some conditions the relative rating of fuels will be changed when inlet-air temperature or velocity is changed. Likewise, the relative rating may be changed by changing the fuel nozzle to modify the fuel-spray angle or the injection pressure.

Under sea-level operating conditions in an operating turbo-jet engine, fuels of different volatility and molecular structure showed no discernible differences in combustion efficiency. At a simulated altitude of 45,000 feet at about 75 per cent. rated engine-rotor speed, differences appear as shown in Figs. 32 and 33. Increasing the boiling point decreases the combustion efficiency for a given type of fuel. The aromatic fuel types give lower combustion efficiencies than other fuel types with the same boiling point.

Carbon deposition is most severe at sea level, and the amount of carbon deposited decreases with increasing altitude. Investigation of a number of fuels on combustors of different design, indicates that the carbon-forming tendency can be correlated with hydrogen-carbon ratio and volumetric average boiling temperature of fuel. A plot of this relationship for an annular combustor is shown in Fig. 34. If one proceeds vertically from the volumetric average boiling temperature to the proper hydrogen-carbon-ratio line, and then horizontally to plot the amount of carbon formed with each fuel, the data form a straight line for a series of

fuels. The position and slope of the line will vary for different operating conditions. The amount deposited increases with decreasing hydrogen-carbon ratio and with decreasing volatility.

RESEARCH AS FOUNDATION FOR ADVANCED DEVELOPMENT

A type of organised research effort which has become increasingly important is that which is focused on some advanced development, the completion of which may not yield immediately a practically useful device, but which, by stimulating and channeling group effort, will create scientific and technical data and experience which will result in a more rapid rate of progress. The great task of research leadership is to select definite and challenging goals of wide appeal so that effort is directed into the needed areas through the interest of the individual in accomplishing an interesting and difficult task.

THE RESEARCH-AEROPLANE PROGRAMME

The most interesting example of this type of research is the co-operative programme among the N.A.C.A., the Air Force, the Navy, and several aeroplane manufacturers for the construction of and flight research on aircraft intended solely for research in the transonic and supersonic region. Unfortunately, this story cannot be completely told at this time; but it seems worth while to describe how this project originated and developed, and to discuss its true significance for aeronautical development.

The research-aeroplane programme had its origin in 1944 in the need for aerodynamic information at speeds near the speed of sound and the inability of wind tunnels to give the required data because of blocking. In discussions of this problem in numerous quarters, including N.A.C.A. staff conferences, N.A.C.A. Aerodynamics Committee, and elsewhere, the possibility of using piloted aircraft was discussed, along with the freely-falling-body method and the wing-flow method which seemed to offer the most immediate promise. John Stack, of the N.A.C.A. Langley Laboratory, was a vigorous advocate of the use of piloted aircraft; and under his direction some studies were made of the possible configuration and dimensions of such an aeroplane. The aeroplane was to be made as small as practical and to carry no load other than the pilot, fuel, and research instrumentation. It was in no sense to be regarded as a tactical aeroplane.

Fig. 34.

Correlation of carbon deposition with volumetric average boiling temperature and with hydrogen-carbon ratio for various fuels.

Within a few months the project for a research aeroplane received general support, and it was agreed that the Air Force, Navy, and N.A.C.A. would undertake a co-operative programme involving eventually a number of aeroplanes. The Air Force contracted with the Bell Aircraft Corporation to design and construct the X-1, to be propelled by a rocket motor; and the Navy contracted with the Douglas Aircraft Company to design and construct the D-558-I, to be powered with a turbo-jet engine. The general dimensions and characteristics were determined early in 1945. N.A.C.A. undertook to conduct necessary wind tunnel tests, to install flight-test instruments, and to analyse the data; and subsequent to the initial tests, to conduct a systematic flight-test programme.

The X-1 was the first aircraft to be completed under the programme. There was some delay in completing the rocket motor, so that a decision was made to carry the X-1 to high altitude on a B-29 aeroplane and fly it as a glider. When this was found to be a relatively simple procedure, it was decided to launch the flights with power in the same way so that the time available for research measurements could be extended. The first flight without power was made in the spring of 1946; and the first flight with power, on 9th December 1946. On 14th October 1947, the X-1 exceeded the speed of sound in horizontal flight at high altitude. The D-558-I made its first flights in 1947;

and in August of that year, broke the official World Speed Record, since exceeded by the F-86.

Both of these aeroplanes utilise conventional subsonic wing configurations, without sweepback, and of comparatively low aspect ratio. Their aerodynamic design was not regarded as optimum for supersonic speeds; they were built to verify results obtained by other test methods and to study further the behaviour of conventional configurations in the transonic region. The aeroplanes were kept as small as possible so that the control forces could be kept within the capabilities of the pilot, and they were designed to withstand loads of 18 times their weight. By operation at high altitude the control forces were further reduced by the low density; and by making the exploratory flights in a horizontal or climbing flight path, speed could be reduced by shutting off the power, as contrasted with the danger of exploring a new aircraft in a dive, in which the force of gravity cannot be turned off to reduce speed. An adjustable stabiliser was provided to enable compensation for trim changes and the reduction of control forces. Only a rocket could furnish sufficient thrust to drive this configuration at supersonic speeds, and then only at high altitude where the drag is reduced because of the reduced air density.

The success of these aeroplanes should not be interpreted to mean that the expected undesirable characteristics did not occur. The aeroplane was so designed and operated that these characteristics could be handled by the pilot. I hope the time will soon come when the characteristics of this conventional configuration, which is obsolete so far as the design of modern transonic and supersonic aeroplanes is concerned, may be made generally available.

The programme was soon enlarged to include configurations which are indicated by other test methods to be more satisfactory at transonic and supersonic speeds. The D-558-II and the X-2, with swept-back wings, were added; and the D-558-II is making its early flights now. Other research aeroplanes may be added later.

The significant results of this programme are not the speed records but the quantitative data being obtained on drag, stability, trim changes, air loads, and so on, at all speeds within the capabilities of the aircraft. The chief interest is in that region within which large changes in characteristics occur, which is different for different aeroplanes in the series. The expected phenomena are known to some extent from wind tunnel data, dropped-body tests, wing flow tests, and rocket-propelled model measurements. Research aeroplanes give the final check.

An unexpected result has been the psychological effect of the research aeroplane flights in dispelling fear of unknown and unanticipated phenomena in the transonic region, and engendering new confidence in the use of models in wind tunnels and free flight as a means of obtaining design data for use in the design of tactical aeroplanes. Knowledge of a difficult problem stimulates ingenious men to find methods of overcoming the difficulties.

The research-aeroplane programme has been of continuing value in providing a unifying influence for large parts of the N.A.C.A. research programme. The programme was backed up by numerous wind tunnel investigations and investigation by other techniques; but in addition, it provided new incentives for understanding stability and control, methods of pilot escape, aerodynamic heating, scale effect, and similar general problems.

Why not research power plants?

It has not yet seemed expedient to propose the development of research power plants comparable to the research aeroplane, because of the much higher cost of development and because a somewhat similar stimulus and focusing of research can be accomplished by dealing with the components. The basic requirements of aircraft gas-turbine power plants are high output for a given air flow, low fuel consumption, minimum weight, satisfactory endurance, and minimum investment in critical materials. The direction of research to improve performance is obtained by making theoretical analyses of the gas-turbine cycle for various operating conditions. The result of such an analysis of the turbo-jet engine at a flight speed of 1,000 miles per hour at sea level, with the assumptions noted, are shown in Fig. 35. Such analyses show that improved fuel consumption is to be obtained mainly by increasing the compression ratio, and improved specific thrust mainly by increasing the turbine inlet temperature. They suggest research on compressors to increase the compression ratio per stage; and, since the turbine inlet temperature is limited by the high-temperature properties

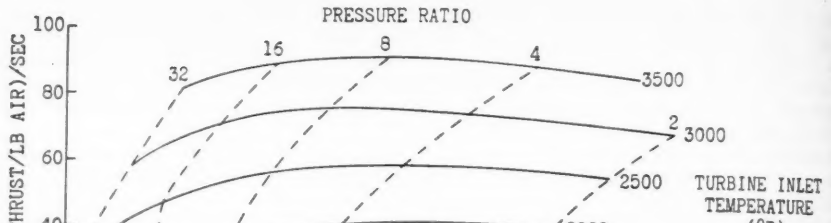


Fig. 35.

Specific fuel consumption and specific thrust of turbo-jet engine for flight speed of 1,000 m.p.h. at sea level. (Compressor efficiency 85%, turbine efficiency 85%, diffuser efficiency 100%, jet efficiency 100%, combustion efficiency 100%, no heat loss.)

of the blade materials, research on blade materials and on means for cooling the blades[28].

Figure 35 also shows that the lowest fuel consumption for a given turbine inlet temperature is obtained at some sacrifice in specific thrust; if maximum specific thrust were the sole criterion, the maximum would be obtained at values of the specific fuel consumption of 1.2 to 1.4. Such necessity for compromise is the everyday business of the designer.

The direct solution of the problem would be the development of improved heat-resistant materials. J. H. Collins, junr., of the N.A.C.A. Lewis Laboratory, has provided the following summary of the status of this field.

The possibility of improving performance by increasing the temperature of operation has inspired the metallurgists of the world to seek materials having stable structures at high temperature that are more refractory than those in current use. Although each selection of a material for a turbine part poses a variety of metallurgical problems, only those will be discussed that are associated with the turbine blade, which experience indicates to be one of the critical engine components. Drawing on meagre experience available in other fields, American metallurgists during the past war introduced a large number of alloy compositions. Selection of most of these materials was based on the knowledge that austenitic-base alloys are inherently stronger at high temperatures than ferritic-base alloys, and on the knowledge that cobalt, tungsten, molybdenum, titanium, and columbium, will in general improve the strength of steel at elevated temperatures. A few of these war-born materials exhibited superior properties and permitted increases in turbine operating temperatures. An important goal was the achievement of large-scale production, and many promising materials were eliminated because of fabricating difficulties encountered in trying to handle the materials under normal production processes. Ease of fabrication probably accounts for the general usage of cast alloys, inasmuch as both the casting technique and handling procedures were immediately available, as well as the basic alloys. Since the war, metallurgists have had an opportunity to survey the field more leisurely, and a concerted effort has been made to improve handling and processing procedures.

Materials currently in use in America permit operation under conditions of high stress up to material temperatures of 1,450°F. Certain materials in production will potentially permit operation up to 1,600°F. New alloy systems under investigation, such as those of chromium-base alloys, give promise of extending this maximum temperature slightly, but the greatest hope for real temperature increases

appears to lie in the use of certain intermetallic compounds or of ceramic-containing materials. Most of these materials require more ductility and improved thermal shock resistance, and much research must be done to make them acceptable for use.

Pure ceramic materials of oxide base have been developed by the National Bureau of Standards to the point where 100-hour stress-rupture strengths of 17,000 and 16,000 psi are available respectively at 1800° and 1900°F, as compared to about 12,000 psi at 1800°F for the best production high-temperature alloys. In addition, the specific gravities of these ceramics are less than one half the specific gravities of the alloys, which is important in its effect on the stresses induced in rotating parts such as turbine blades. Ceramics of carbide base have been hot-pressed and sintered to yield short-time tensile strengths of 22,000 psi at 1800°F which, on a strength-weight basis, is superior to those of the alloys. Moreover, at temperatures of 2200°F, carbide-base ceramics have been found to have short-time tensile strengths as high as 16,000 psi, which is above the tensile strength of the best high-temperature alloys. It might be noted that the molybdenum and tungsten-base alloys give promise of high strength at very high temperatures, but these materials are still in undeveloped states, and no prediction as to their properties can be made.

Combinations of metals and ceramics, termed "ceramals" by the N.A.C.A., appear to possess outstanding properties at elevated temperatures. In particular, the carbide-base ceramics, when combined with transition metals such as cobalt and nickel, possess short-time tensile strengths as high as 33,000 psi at 1800°F (about the same as the tensile strengths of alloys) and strengths of 14,000 psi at 2200°F, which are outstanding when compared on the basis of strength-weight ratio. The predominant deficiency of carbide-base materials is their susceptibility to oxidation at elevated temperatures, a problem that must be handled by coating with a corrosion-preventing material or by so compounding the ceramal, or ceramic, that resultant oxide coating grows at a very slow rate. Some success has been attained in such attempts and carbide-base ceramals have been operated for short periods of time as gas-turbine blades at gas temperatures as high as 2200°F. The thermal conductivity of a particular carbide-ceremal turbine blade was twice as great as that of commercial high-temperature alloys so that, for the same gas temperature, the ceramal blade operated appreciably cooler than alloy blades on the same wheel.

No matter what may be the course of development of materials, the development of turbine cooling may be used by the designer either to increase the specific thrust still further, or to make possible the attainment of present performance with a reduced or even zero investment in strategic metals. It was this latter problem which originally introduced the subject in Germany during World War II, where successful air-cooled turbines for turbo-jet engines were produced from relatively low-alloy materials.

The apparent simplicity of the early attempts is misleading in many respects. While cooling at present-day turbine temperatures does not offer serious difficulties, the study of high-performance cooled engines involves many additional complications. The performance of a cooled engine will inevitably be inferior to a similar uncooled engine using better heat-resistant materials, and the cooling requirements depend on many variables associated with the specific design of power plant and its operating conditions. The total problem, therefore, is one of the economics of the entire propulsion system, advantages of cooling as related to the use of non-critical materials, energy balances, and net gains in performance. The losses associated with cooling can readily become excessive unless refined techniques, based on reliable and comprehensive data, are used in design and analysis. Thus an advanced development of this type must be supported by extensive research along many lines.

Analytical comparisons have been made of the effectiveness of rim cooling, air cooling, and liquid cooling. The possibilities of rim cooling, whereby heat is conducted from the blade to the rim, are very much inferior to the possibilities of liquid or air cooling of the blades. Fig. 36 shows some typical configurations which have been analysed.

The analyses are dependent on heat transfer data, but few data are available for the high temperatures and pressures expected to be encountered. This suggests research of a systematic nature to establish empirical relationships between various dimensionless parameters for various blade shapes and operating conditions. Such work is under way in static cascades of cooled blades and in experimental cooled turbines.

These studies in turn suggest still more basic studies, since the heat transfer at any point is determined by the development, local condition, and past history of the boundary layer. Ultimately one would like to be able to compute the heat transfer from a computed or measured velocity distribution, determining the boundary-layer development including velocity and temperature profiles, but this is probably a long way off.

Since space is required within the blades for cooling, this suggests an orientation of theoretical work on flow through cascades to relatively thick blades of shapes adapted to provide the necessary internal passages. The problem of computing the velocity of a compressible fluid over the surface of turbine and compressor blading has been under study at the N.A.C.A. Lewis Laboratory. In the absence of a well-developed theory a variant of Flügel's treatment has been used in the design of several sets of turbine blades. The simplifying assumption is made that the curvature of the stream lines varies linearly between the suction and pressure surfaces. Surface velocities predicted by this simplified analysis have been compared with measured surface velocities for the pitch section of a gas-turbine stator designed by this stream-filament theory. Fig. 37, showing reasonable agreement, was shown by A. Silverstein in the 1948 Wright Brothers Lecture.

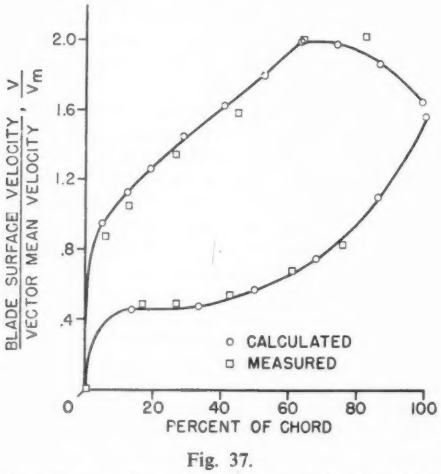


Fig. 37.
Comparison of measured and calculated turbine-blade surface velocities.

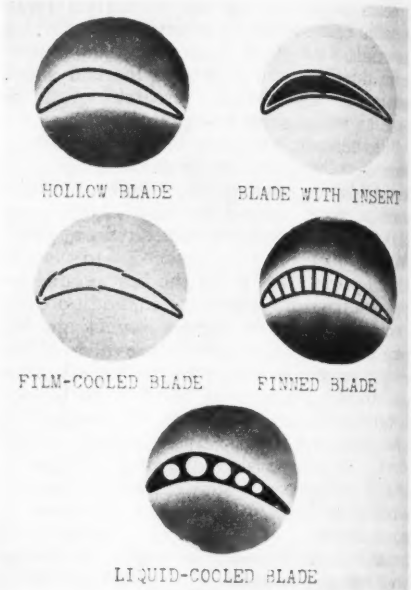


Fig. 36.
Cross-sectional views of various air-cooled blades and a liquid-cooled blade.

Figure 38 shows the results of an analysis to compare the various blade configurations for air cooling, and Fig. 39 illustrates the effect of blade material for one configuration. The analysis is very approximate, since a constant heat-transfer coefficient was assumed. The allowable effective gas temperature for 1,000-hour predicted blade life is plotted against dilution. Finned blades show promise of immediate application if suitable techniques of fabrication can be developed.

Research is required on the heat-transfer process in the internal passages, since currently-available information is insufficient.

Research is required on the limits of permissible bleeding of cooling air from the compressor. In a turbo-jet engine the cooling air is reintroduced into the cycle with the heat-loss energy added to it before it enters the jet nozzle.

On the basis of the available knowledge, which is mostly analytical, it is believed that air-cooled turbines will permit operation in a turbo-jet engine at 2500°R turbine inlet temperature with the best non-strategic-metal blades and at 3000°R with high-temperature

alloys. Liquid cooling offers even greater promise, though with added complication.

It is readily seen that setting the goal of an advanced and currently-impractical component performance is a useful means of enlisting research effort on interesting and challenging problems which will almost certainly expedite the attainment of improved performance. The compressor and the combustion chamber offer equally fertile opportunities.

SUPPORT OF SPECIFIC APPLICATIONS

The final type of research activity to be considered is that in support of specific applications. In the United States such applied research is conducted for the most part by the industrial groups engaged in the development of specific aeroplanes, engines, or aircraft components. In the aerodynamic field many companies have excellent wind tunnel facilities; and in addition, there are available for industry use the Co-operative Wind Tunnel at the California Institute of Technology, owned by five of the major aircraft companies and operated by C.I.T., and the Cornell Aeronautical Laboratory at Buffalo. In the propulsion field, the major companies have, or will soon have, excellent facilities for development. With the increasing speeds of aircraft and the increasing size of engines, the cost of the larger facilities becomes too great for the resources of industry, and definite plans have been proposed for the construction of supersonic wind tunnels to be operated by the government, but available for development research on specific aircraft.

The special facilities of the N.A.C.A. have been made available on request of the military services for such specific research on projects of major national importance, after the completion of investigations that can be made in facilities available elsewhere. In the case of one of our operational military aircraft the N.A.C.A. conducted an extensive programme on a 1/14-scale model in the 19-foot wind tunnel, including measurements of lift, drag, longitudinal stability and control, downwash at the tail, lateral stability and control, aileron effectiveness, and other characteristics at the stall. Measurements were made on a 4/29-scale model of the wing in the same wind tunnel. Tests were made at high subsonic speeds on a 1/11-scale model in the 16-foot high-speed

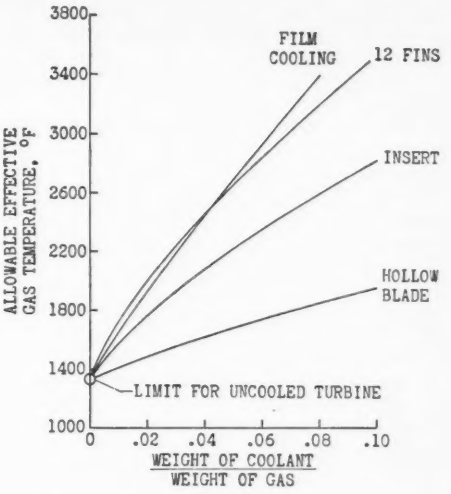


Fig. 38.

Cooling effectiveness of various blade configurations for air-cooling of S-816 high-temperature alloy blades.

wind tunnel, including limited data on pressure distribution, as well as lift, drag, stability and control. A 1/6-scale semi-span model of the tail was used in the 7- by 10-foot wind tunnel for the study of control-surface balancing and tab design. The nacelle design was studied in the two-dimensional low-turbulence wind tunnel. Ditching tests were made on 1/20- and 1/30-scale models in the tank.

Similarly, the special facilities of the Lewis Laboratory have been used to study

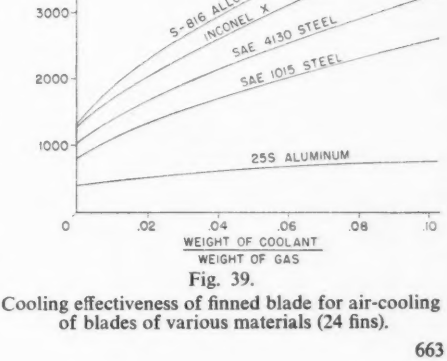


Fig. 39.

Cooling effectiveness of finned blade for air-cooling of blades of various materials (24 fins).

compressor performance, turbine performance, and combustion-chamber performance, under high-altitude conditions, in connection with the development of specific engines.

The degree to which N.A.C.A. facilities are used for specific tests has varied greatly between wartime and peacetime. The Industry representatives, when speaking collectively rather than individually, prefer general rather than specific programmes as of the greatest national benefit.

CONCLUDING REMARKS

I have tried to sketch for you my view of the aeronautical research scene and to interpret its meaning by a few examples. If you are impressed by the perhaps undue emphasis on aerodynamics, you may blame my previous experience. I should remind you, however, that the last Wright Brothers Lecture in the United States by A. Silverstein contains a very comprehensive review of the power-plant field, and refer you to it for supplementary reading. If the United States or the N.A.C.A. contribution appears unduly prominent, this also reflects the observer. As to the many other aeronautical sciences, I plead lack of space. Their contributions are no less important to aeronautical progress.

The aeronautical research scene is part of a larger territory which covers all of the diversified activities connected with the development, production, and use of aircraft. Progress is made by continually building on an increasing body of knowledge. Research is the key vitamin in promoting this growth. If it were absent, growth would cease as soon as the accumulated supply of knowledge was fully exploited by practical application.

The results of research make the most enduring contribution when the research worker aims at the understanding of phenomena, going beyond the mere collection and tabulation of data arising from empirical tests. Hence the research group feels the necessity for initiating and supporting long-range programmes which lay the groundwork for the future. The research group has an independent responsibility for deciding what is needed to keep research knowledge ahead of application. The group should by no means become a service group with programmes determined solely by the current needs of to-day's aircraft. There is no surer way to perpetuate the old and ignore the new, than to determine the research programme solely on the basis of to-day's production and procurement problems.

Having asserted the claim of research to independent planning, let me add that the research programme must be a well-rounded one. It should not in its entirety be limited to exploratory research or to co-ordinated theoretical and experimental work on experimental situations where complete understanding of basic phenomena is the principal goal. The needs of designers for systematic surveys of various areas and for research in support of development, must be recognised and promoted by frequent and close contact between designers and research workers. The selection of some common advanced technical development as the goal of both groups, has proved to be an excellent means of promoting co-operation and of channeling research into directions permitting early application, without sacrificing the values inherent in the personal enthusiasm, initiative, and freedom of the research worker.

Acknowledgment is due to many N.A.C.A. colleagues for assistance, in particular to I. H. Abbott, who has taken many of the mechanical burdens and contributed helpful criticism.

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Sir John Buchanan, proposing a vote of thanks, said that a mere formal vote of thanks was quite inadequate to express proper appreciation of the work and care that had gone into the preparation of the lecture.

The Wilbur Wright Lectures were becoming classics, not only to the Royal Aeronautical Society, but to all those who were engaged in research and development of the science and art of aeronautics. Indeed, they were more than that; they were the outward and visible sign of the ties which bound the English-speaking peoples of the world, and those people engaged in aeronautics could claim to have made closer ties with their friends in America and in other English-speaking

nations than any other group of people. At no other time in the history of the world had there arisen so great a necessity as that which existed at the present time to demonstrate the effects of those ties.

The Society looked forward keenly to the forthcoming Conference in New York with the Institute of the Aeronautical Sciences; to visiting Dr. Dryden in his spiritual home and to seeing, not only in the flesh but in actual operation, much of the research work which he had dealt with so admirably in his lecture.

Professor A. A. Hall, seconding the vote of thanks, said that when the Society invited a lecturer to undertake the Wilbur Wright Lecture it was sought to confer a great honour upon him, but nevertheless it presented him with a most arduous task. He had in his hands the commemoration of a great pioneer in the aeronautical profession, and he was faced by a critical audience; furthermore, he knew that his contribution would be judged against a distinguished background of the Wilbur Wright tradition.

Dr. Dryden had measured excellently to his task, and that he had done so was no surprise to those who were acquainted with his work and his career in aeronautical research. He had made many personal contributions of a high standard to factual data, to experimental technique and to analysis in connection with problems which had been puzzling from time to time. Not the least of Dr. Dryden's contributions to aeronautical understanding was his great ability as an expositor of difficult technical matters, which had just been demonstrated.

It would appear that Dr. Dryden, having had a most distinguished career in scientific research, had now turned towards statesmanship, if one could judge from his remarks on the Budget Committee, and his equal distinction in that field would be expected.

The vote of thanks was received by the meeting with acclamation.

Following the Lecture the Annual Council Dinner was held at 4 Hamilton Place, at which the following were present:—

Brigadier General John B. Ackerman, Military Air Attaché, U.S. Embassy.

Sir John S. Buchanan, C.B.E., A.M.I.Mech.E., F.R.Ae.S., President-elect; Major G. P. Bulman, C.B.E., B.Sc., F.R.Ae.S., Council member.

S. Camm, Esq., C.B.E., F.R.Ae.S., Council member; Air Marshal The Hon. Sir Ralph A. Cochrane, K.C.B., K.B.E., A.F.C., A.F.R.Ae.S., Air Officer Commanding-in-Chief, Flying Training Command; Dr. Cornell, Planning Director, Research and Development Board, U.S.A.; Dr. H. Roxbee Cox, D.I.C., B.Sc., F.I.Ae.S., F.R.Ae.S., President.

Sir Charles G. Darwin, K.B.E., M.C., F.R.S., Director, The National Physical Laboratory; Dr. H. L. Dryden, Hon.F.I.Ae.S., F.R.Ae.S., Wilbur Wright Memorial Lecturer.

Air Marshal A. B. Ellwood, C.B., D.S.C., Air Officer Commanding-in-Chief, Bomber Command.

W. S. Farren, Esq., C.B.E., F.R.S., F.R.Ae.S., Council member.

Air Marshal Sir R. Victor Goddard, K.C.B., C.B.E., M.A., Member of Air Council for Technical Services.

T. G. N. Haldane, Esq., President, Institution of Electrical Engineers; Professor A. A. Hall, M.A., F.R.Ae.S., Council member.

E. T. Jones, Esq., O.B.E., M.Eng., F.R.Ae.S., Council member.

E. A. Lister, Esq., Civil Air Attaché, U.S. Embassy.

P. G. Masefield, Esq., M.A., F.R.Ae.S., Council member.

Sir Frederick Handley Page, C.B.E., F.R.Ae.S., Past President; The Rt. Hon. Lord Pakenham, Minister of Civil Aviation; W. G. A. Perring, Esq., F.R.Ae.S., Vice-President; Brigadier General J. F. Phillips, Air Force Secretary to Research and Development Board, U.S.A.; Captain J. Laurence Pritchard, Hon.F.I.Ae.S., Hon.F.R.Ae.S., Secretary of the Society.

N. E. Rowe, Esq., C.B.E., B.Sc., D.I.C., F.R.Ae.S., Vice-President.

The Rt. Hon. Lord Sempill, A.F.C., F.R.Ae.S., Past President; Dr. H. Shaw, Director, Science Museum; Sir Richard Southwell, M.A., Ll.D., F.R.S., F.R.Ae.S.

W. Tye, Esq., B.Sc., F.R.Ae.S., Council member; Sir Frederick Tymms, K.C.I.E., M.C., F.R.Ae.S., United Kingdom Representative on Council of I.C.A.O.

Captain C. F. Uwins, A.F.C., O.B.E., F.R.Ae.S., Council member.

Dr. E. P. Warner, M.S., B.A., D.Sc. (Hon.), Hon.F.I.Ae.S., Hon.F.R.Ae.S., President of Council, I.C.A.O.; Sir Robert Watson-Watt, C.B., D.Sc., Ll.D., F.R.S., F.R.Ae.S.; Dr. H. C. Watts, M.B.E., D.Sc., M.Inst.C.E., F.R.Ae.S., Council member; Mr. L. A. Wingfield, M.C., D.F.C., A.R.Ae.S., Solicitor to the Society.

PLANNED FLYING AND PLANNED SERVICING IN THE ROYAL AIR FORCE AND THE EFFECTS OF AIRCRAFT DESIGN ON MAINTENANCE

by

Squadron Leader E. A. HARROP, O.B.E., A.F.R.Ae.S., R.A.F.

The 767th Lecture was read before the Royal Aeronautical Society on Thursday, 17th February 1949, at the Institution of Civil Engineers, Great George Street, London, S.W.1. Dr. H. Roxbee Cox, D.I.C., F.R.Ae.S., F.I.Ae.S., President of the Society, introduced the Lecturer, Squadron Leader E. A. Harrop, O.B.E., A.F.R.Ae.S., R.A.F., of the Department of the Air Member for Technical Services, Air Ministry, and a serving engineer officer of long experience in the Royal Air Force.

PART I

1. INTRODUCTION

The title of my lecture is "Planned Flying and Planned Servicing in the Royal Air Force and the Effects of Aircraft Design on Maintenance" in which I hope to show how the Royal Air Force has evolved a system of planning for controlling its flying and servicing operations to achieve greater economy of its resources and the influence that aircraft design has on this aim. My object is to suggest how aircraft designers can help to further improve this economy by greater attention to those details in aircraft construction which have an adverse effect on maintenance costs.

The title covers a wide subject with many conflicting issues, but I consider there is so much inter-action between flying, servicing, maintenance* and design that it is impossible to separate them and get a balanced view. Because of this and the limited time at my disposal I can only cover some of the main aspects with the help of a number of illustrations and some over-simplification of the problems.

In spite of the witticism of somebody that "flying and economics are a contradiction in terms," I must stress that my subject is essentially a study of the economics of flying and its maintenance in the Royal Air Force, which has rather different yardsticks of measurement than those by which the efficiency or economy of civil operations are judged.

Mr. N. E. Rowe in his lecture to the Society in December 1947,† stated in connection with economy, "The fundamental factor is the aeroplane. This is the

*The definition of "Servicing" and "Maintenance" in the R.A.F. is as follows. "Servicing" embraces all the technical activities covered by such operations as inspection, repair, reconditioning, modification, certain aspects of salvage work and arming, loading or missile preparations (*see* Appendix "C" for further details). "Maintenance" embraces the activities of production, supply, storage, overhaul, spares and the larger aspects of salvage. For the sake of wider interpretation I have chosen to use the term "servicing" for specific servicing operations on aircraft or components and "maintenance" as an all-embracing term for supporting flying operations in its general sense, which includes all servicing and supply aspects.

†N. E. Rowe. The Problems Facing Civil Air Operations. Journal R.Ae.S., February 1948.

Fig. 1.
Comparative weight of bombs dropped per national man-month expended for three types of bomber aircraft in 1943.

revenue earner and if, because of its inherent bad qualities such as low relative payload, high unserviceability, poor maintenance features and so on, its direct cost of operation is high, then no amount of administrative excellence in reducing overheads will make the operations economic." In my opinion this statement is no less true for military operations. Fig. 1 illustrates this: in 1943 the relative efficiency of three different types of bomber aircraft was examined in terms of total bombs dropped on the enemy for the total man-months of work expended by the Nation in the production and maintenance of the aircraft, including the effort required to replace wastage by operations and training.

The figures shown, although very rough estimates, were illuminating. Obviously many things contributed to the relative success of the aircraft for bombing operations; aerodynamic efficiency, operational and administrative efficiency, ease of production and ease of servicing and maintenance were all, more or less, contributory factors. But for the Royal Air Force they raised the pregnant question, "What are we getting for our money? Can we get more? If so, how?" These and similar questions were asked by all commanders during the last war, and since then, under the urge of man-power economy, if not in terms of bombs, in terms of trained air crews per aircraft, or flying hours per aircraft, or flying hours or ton miles per servicing man-hour, and so on.

The answer to these questions was the development of a more logical system of planning and administration, more sensible methods of servicing and a better appreciation of maintenance design requirements which I will describe under the following headings:

(*a*) The Origins of Planned Flying and Planned Servicing.
(*b*) Planned Flying.
(*c*) Planned Servicing.
(*d*) Rationalisation of Methods.
(*e*) Maintenance Design.
(*f*) Comparative Costs.

2. THE ORIGINS OF PLANNED FLYING AND PLANNED SERVICING

The name "Planned Flying and Planned Servicing" was given to a system of planning and administration of flying and servicing in the Royal Air Force whose origin and growth was a natural consequence of the development of aircraft, tremendously accelerated during the last war by the increasing problems of flying operations and the resulting loads placed on the maintenance and training organisations.

Moreover, the transition from the relatively simple aircraft of the early thirties to the aircraft of to-day has been rapid and aircraft development jumped far ahead of maintenance appreciations. The R.A.F. was suddenly given new four-engined stressed skin aircraft, new wireless aids, radar was introduced, more electrical equipment, bigger and more complicated and powered gun turrets, hydraulic and pneumatic services and so on in bewildering array. Ever-increasing numbers of more highly qualified tradesmen were required to service the new equipment and training establishments had to be considerably expanded to meet the demands for a variety of tradesmen. All branches of the Service were demanding more men—even the W.A.A.F. did not fill the gaps in new establishments—from a limited national exchequer of man power. So it was that under the stringency of wartime economy of man power the first principles of Planned Flying and Planned Servicing were perceived. While new ideas were tried out by all Commands in order to save man-hours, Air Ministry research teams set out to

study flying operational needs and servicing methods and organisation.

Before the war, little, if any, scientific research had been made into the relationships of flying to aircraft serviceability or unserviceability to servicing man power. Establishments of aircraft and men were based on empirical assessments that bore no relation to flying effort. At the beginning of the war there was a tendency to judge the operational efficiency of flying units by the percentage of serviceable aircraft available at any particular moment, without taking into consideration other factors, such as the flying intensity, the weather, the manning state, the incidence of defects, battle damage, scarcity of spares and the like. The standard yardstick was arbitrarily set at 75 per cent. minimum serviceability. This "Serviceability Index" as I will call it, was naturally sponsored by urgent operational necessity at the time, but it was not fully realised that you cannot have maximum serviceability simultaneously with maximum flying effort. It was the age old complex of expecting to "have your cake and eat it too!"

Flying Training Command, by virtue of its role, was the first to recognise a definite relationship between flying intensity and aircraft serviceability; that they were interdependent. From this fact some new yardstick was sought to judge efficiency, but it was soon found that there were other factors to be taken into account, for example further enquiry was necessary into rates of recovery of serviceability, *i.e.* the turn-round times for inspections, repairs, and so on. The weather factor alone considerably influenced the rate of flying.

Thereafter, the Research Team in Coastal Command during the battle of the Atlantic in 1942 formulated a general theory of the principal factors governing the flying and servicing of aircraft from the administrative angle. The elements of this theory can be shown by a simple diagram (Fig. 2) which shows that as the total flying of a squadron of aircraft increases, the number of unserviceable aircraft increases in proportion and the serviceable remainder decreases; whereas the optimum flying intensity per squadron is obtained when all the serviceable aircraft are being flown at maximum daily intensity, that is, when the line falling to the right is continued until the total flying hours equals serviceable aircraft multiplied by their maximum flying intensity. In this example, if the maximum

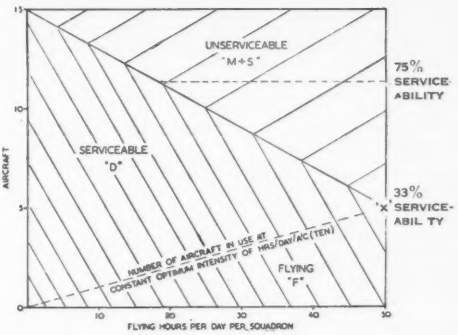


Fig. 2.

Theoretical relationship between unserviceability, serviceability, aircraft in use and intensity of effort.

F = Aircraft flying.
D = Aircraft serviceable (ready to fly).
M = Aircraft awaiting spares, etc.
S = Aircraft undergoing servicing.
X = Maximum utilisation.

intensity per serviceable aircraft is 10 flying hours per day, the total serviceability is only 33 per cent., whereas if 75 per cent. serviceability is demanded, the flying intensity of the serviceable aircraft is only 1.6 flying hours per day. The slope of the unserviceability line, of course, will vary for different types and roles of aircraft. The mathematical treatment of this theory is given in Appendix A, *which contains the essential first principles of PF-PS.*

All these researches clearly showed up the truism that an aircraft does not fly without continual attention, different parts wear out at different times; all are inspected at regular intervals, damage or failure occurs at random but is fairly regular for given intensities, type for type and role for role. In effect continual inspections, repairs and replacements of parts are necessary as flying goes on, so that every hour's flying means many hours servicing on the average, over a period. If servicing stops, flying ultimately stops (and vice versa). In a squadron flying day after day on regular patrols, a large proportion of aircraft is always being worked on in a definite relation. *Therefore, the basis is not merely the relation of men to aircraft, but primarily of flying hours to man-hours of work.*

There are, of course, other factors. For example, it was found that during periods of intensive flying operations serviceable aircraft were not always being flown to

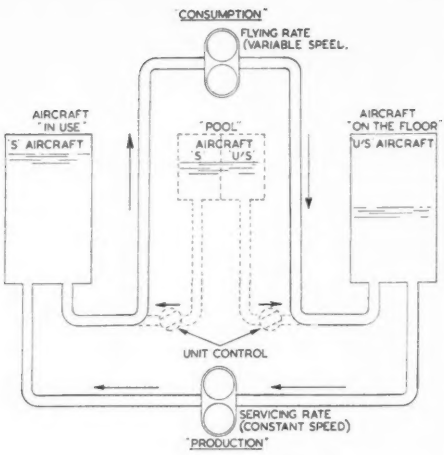


Fig. 3.
Digrammatic relationship between flying and servicing.

capacity, as flying personnel, to avoid fatigue, were not allowed to fly on three successive days or nights. Alternatively, in some cases there were insufficient aircraft for the number of air crews established; some air crews were, therefore, idle for want of aircraft. Each case showed that there was a definite relation between the number of air crews required and the number of servicing tradesmen upon whom the number of serviceable aircraft each day depended. This relationship between flying and servicing is shown in Fig. 3, which also shows the necessity to have some sort of "pool" or reservoir to damp out the inevitable fluctuations between "supply" (servicing) and "demand" (flying) in practice. The elements of the theory of the "pool" are also given in Appendix A.

The outcome of the wartime experience was a system of planning by which large overall economies could be effected, chiefly by reducing the possibilities of wastages in establishments caused by over-insurance of aircraft and men against unknown factors such as weather, peak efforts, battle damage and other variables. Although the varying tasks of the Royal Air Force give rise to many fluctuations of flying and types of aircraft for different roles, they are segregated for planning purposes into three main patterns of opportunity, Fleeting, Variable and Routine. For example, fighter sorties for combat fall into a "fleeting" opportunity pattern, bombing and mine laying into a "variable" pattern, and flying training and air transport services into a "regular" pattern. The general effect of these opportunity patterns on the average state of aircraft, and consequently on the man-power requirements, is shown in Fig. 4.

In order to determine the resources of aircraft and men required for various tasks with varying factors and to eliminate any guess work an instrument known as a "task chart" was devised on which was tabled:—

(*a*) the aim of the task,
(*b*) the variable conditions,
(*c*) the administrative and technical resources available,
(*d*) the operational requirements,
(*e*) the flying plan,
(*f*) the servicing plan,
(*g*) the number of aircraft and men required,
(*h*) the comparative efficiency index for the most valuable resources, *e.g.* aircraft and men in terms of flying hours per aircraft and per man.

The hypothetical task chart shown in Appendix B is in its simplest form as used for a flying training unit with a routine task. The breakdown of the task into parts enables each factor to be examined in detail. For example, how the weather factor influences the number of serviceable aircraft required each day: how the total amount of flying required fixes the average number of unserviceable aircraft each day, from which the total number of servicing personnel required can be calculated. Even the aircraft idle for lack of spares are accounted for. Each set of figures can be examined and efforts made to reduce them. For instance, if the turn-round times for servicing could be halved, the flying potential could be doubled or the aircraft establishment and other overheads halved for approximately the same number of servicing tradesmen. This idea offered the best possibilities of early economies, so it was in this direction that strenuous efforts have since been made which brought forth a system known as "*planned inspection*" which I will discuss later under the heading of Rationalisation of Methods. It was in this later research that many difficulties of maintenance relating to aircraft and component design were encountered. Before discussing these the operational aspects should be considered.

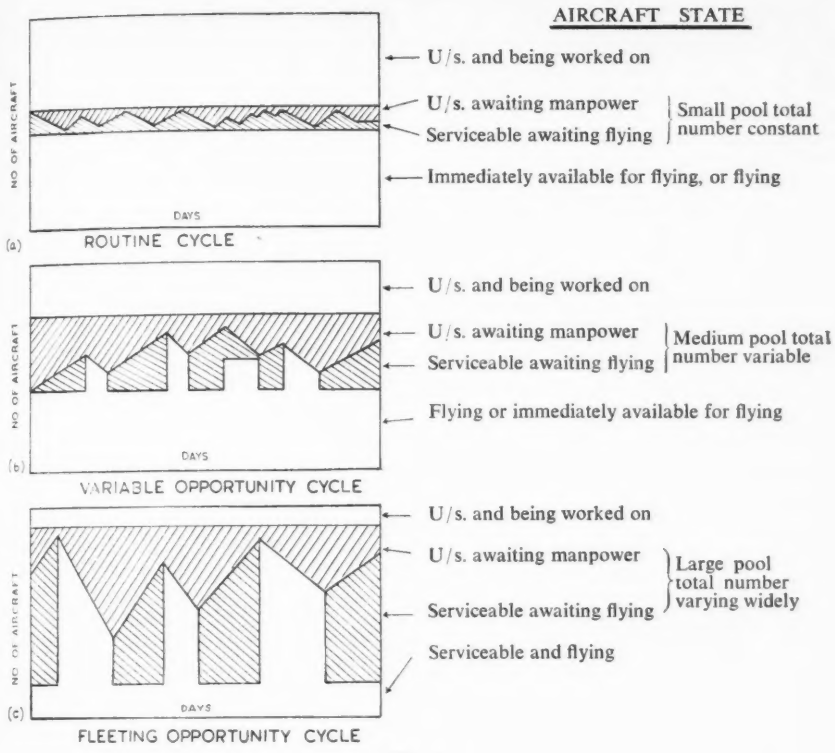


Fig. 4.

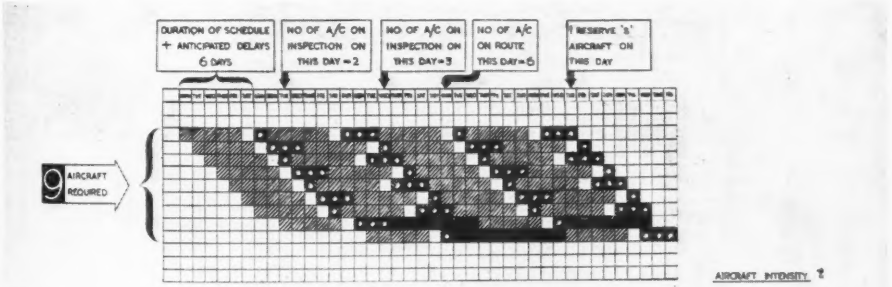

DURATION OF SCHEDULE + ANTICIPATED DELAYS 6 DAYS
NO OF A/C ON INSPECTION ON THIS DAY = 2
NO OF A/C ON INSPECTION ON THIS DAY = 3
NO OF A/C ON ROUTE THIS DAY = 5
1 RESERVE 'S' AIRCRAFT ON THIS DAY
9 AIRCRAFT REQUIRED
AIRCRAFT INTENSITY
TIME SPENT ON ROUTE
AVERAGE DELAY ON ROUTE FROM STATISTICS
TIME SPENT AT BASE ON INSPECTION
AT BASE AWAITING DEPARTURE
EXPLANATORY NOTE
THIS GRAPHICAL METHOD OF CALCULATION IS USED IN ADDITION TO THE THEORETICAL METHOD BASED ON THE NUMBER OF DEPARTURES AND LENGTH OF JOURNEY.
IT SOMETIMES HAPPENS THAT IT IS NOT PHYSICALLY POSSIBLE TO CARRY OUT A SERVICE WITH THE PURELY THEORETICAL NUMBER AND THAT THE USE OF AN ADDITIONAL AIRCRAFT INTERMITTENTLY IS NECESSARY TO MAINTAIN DEPARTURES. SEE LINE 8 & 9
NO OF SERVICES PER MONTH X DURATION OF SERVICE / NO OF AIRCRAFT EMPLOYED
28 X 05 / 9
210 HRS PER A/C PER MONTH

Fig. 5.

Flying and servicing plan for transport aircraft flying to Ceylon.
"U.C." service. One departure daily. Five days return trip.

3. PLANNED FLYING

From the operational point of view flying in the Royal Air Force is mainly opportunist; it rarely follows for any length of time a steady pattern like that in an airline. Moreover, the over-riding requirements of strategy and tactics, mobility and deployment of units, flexibility of organisation, quality, quantity and training of personnel, and so on, tend to make R.A.F. economy a tissue of compromises, as difficult as the design of the aeroplane, to meet all the demands made on it. These are outside the scope of this paper except to note that they almost always conflict with fundamental principles of engineering and economic organisation; for example, the need for mobility and deployment of resources is the antithesis of the static and economic centralisation of those resources; or alternatively, the requirement for the ready availability of serviceable aircraft to meet any emergency (as in Fighter and Bomber Commands), is the denial of the economic utilisation of the aircraft and their associated man power. Therefore, R.A.F. planning and organisation must be geared for widely different commitments. The Berlin Air Lift by Transport Command is a case in point: these resources had to be swung

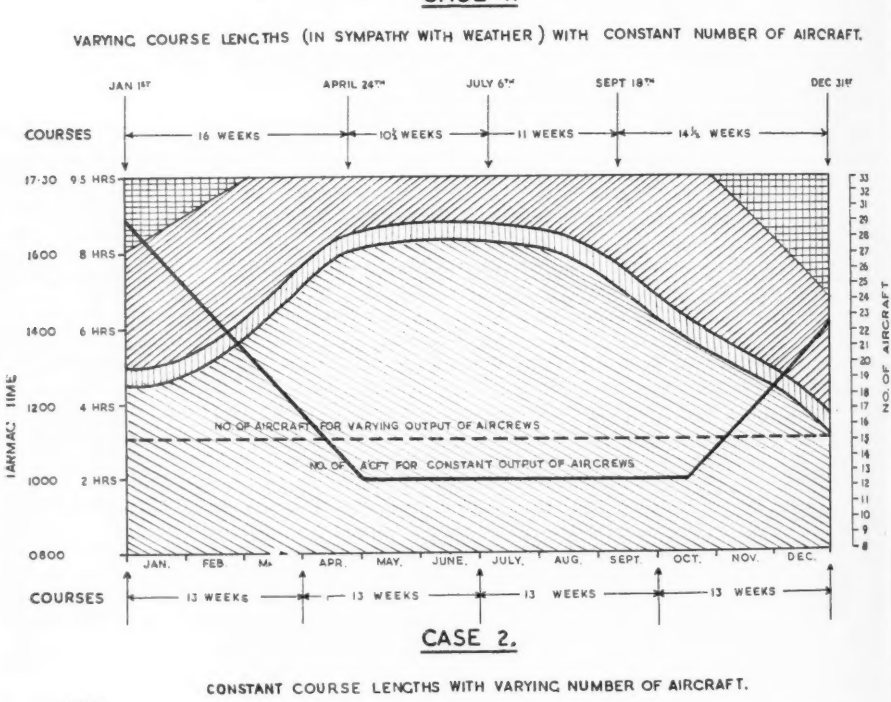


Fig. 6.
Effect of seasonal changes on flying training output.

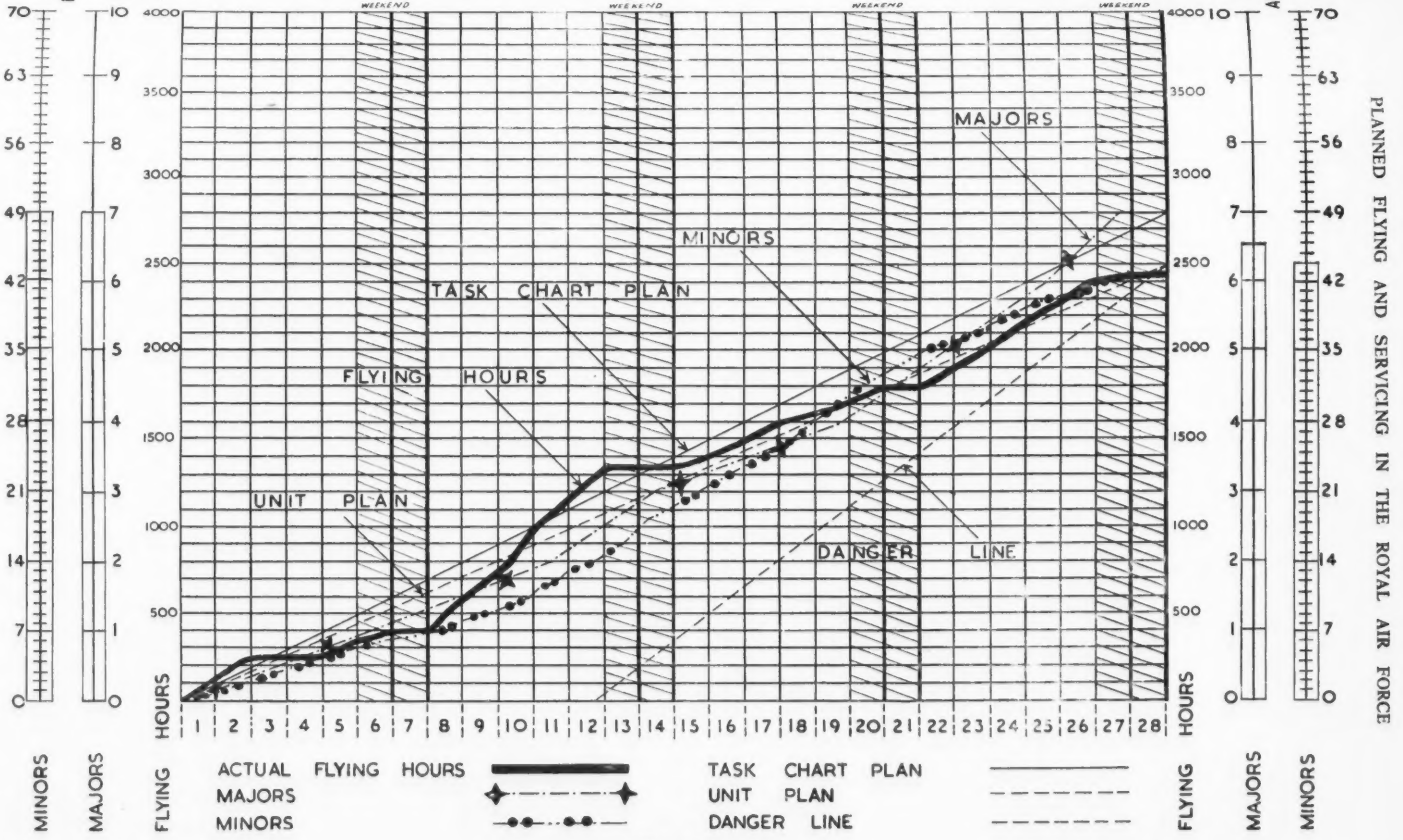


Fig. 7.
Flying and servicing progress chart.

DAILY MANNING STATE

Sub-sections — Second line servicing personnel — Non-effectives

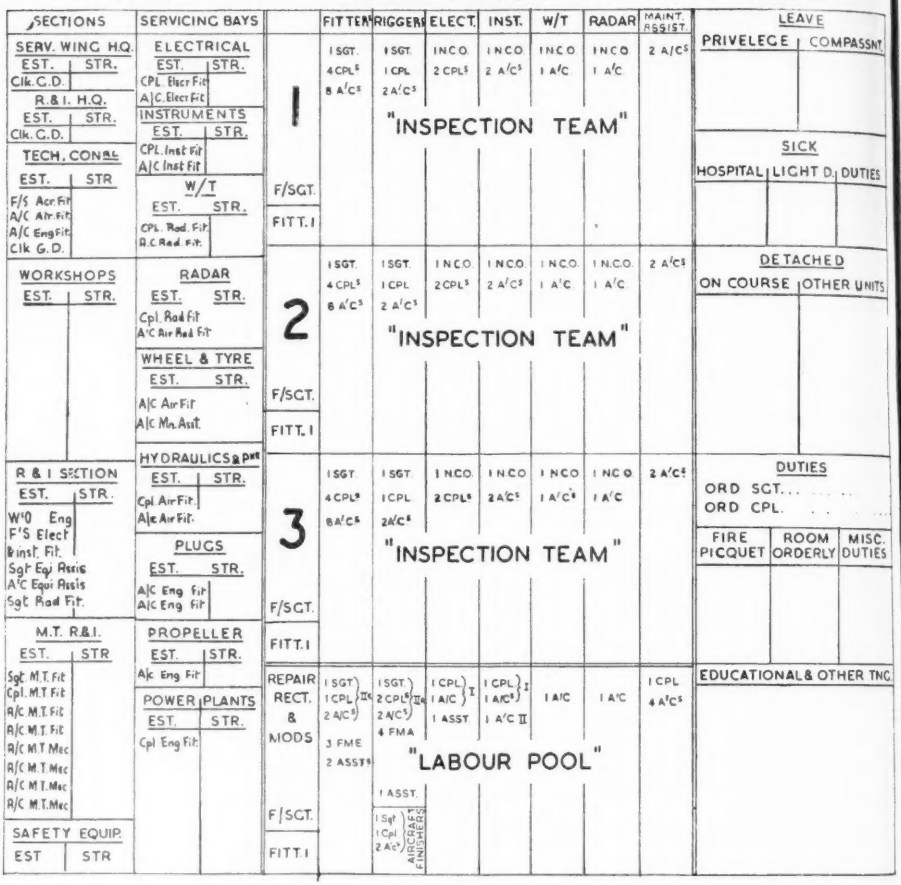


Fig. 8.

practically in a day, from Far East and Middle East air transport services to a concentrated but steady effort to supply Berlin by short sorties, a role for which the aircraft were not designed.

Thus the varying roles of units of the Royal Air Force give rise to many types and fluctuations in the opportunity pattern, so that the most important things to know for planning are the ratio of peak effort to average effort, the approximate duration of periods, of high and low effort and the limiting factors. This is the job of the task chart; to give the overall dimensions of tasks and the average conditions. The following is the way it applies to different R.A.F. operations.

3.1. Bomber operations

Bomber squadrons are generally required to provide "peaks" of effort for individual operations, followed by periods of recovery. Targets are normally plentiful and the limiting factors are the weather and the availability of aircraft and crews which are dependent on the expected wastage rates.

3.2. Fighter operations

Fighter operations generally demand high peak efforts of varying duration and with varying intervals of little or no effort in between, *e.g.* day and night fighters operate at different times in a 24 hour day. In addition it is necessary to know the number of aircraft per unit that must be in the air at any one time to satisfy the tactical situation and the overall number of sorties required on any given day. Intelligence information provides the basis for these assessments.

3.3. Convoy escorts

In operations to protect ocean convoys it is usually possible to obtain well in advance a pattern for the sailings of convoys and their approximate speeds, and from this can be calculated the amount of flying effort that must be expended in escorting them from day to day.

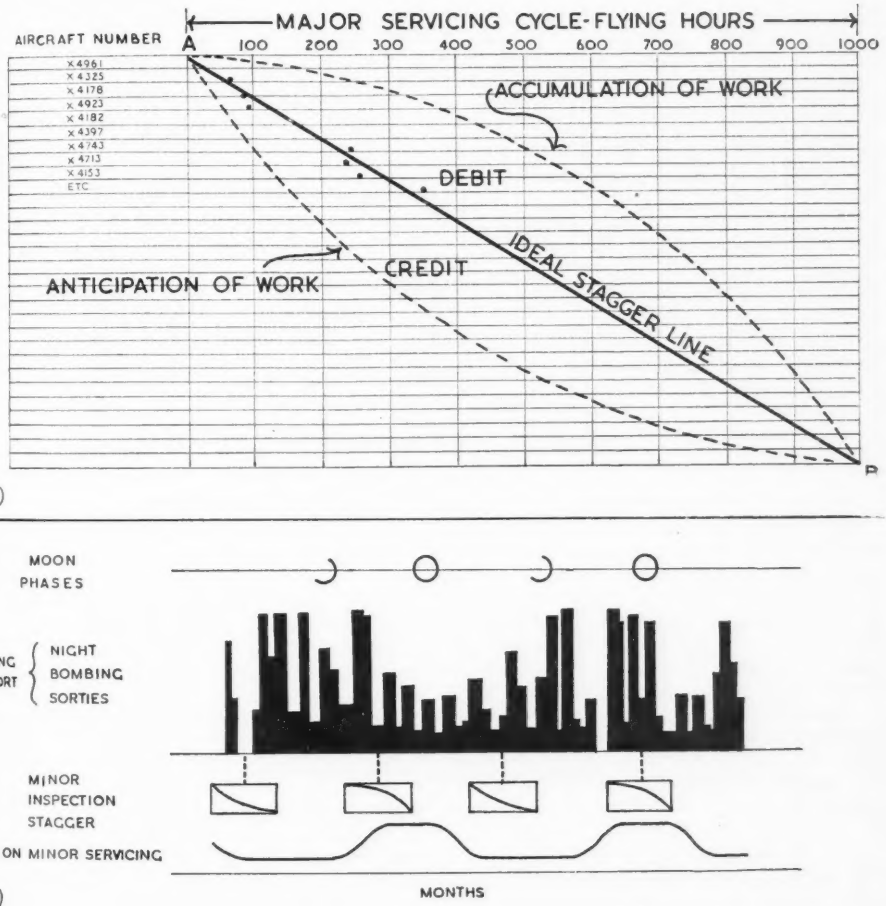


Fig. 9.
Servicing stagger chart.

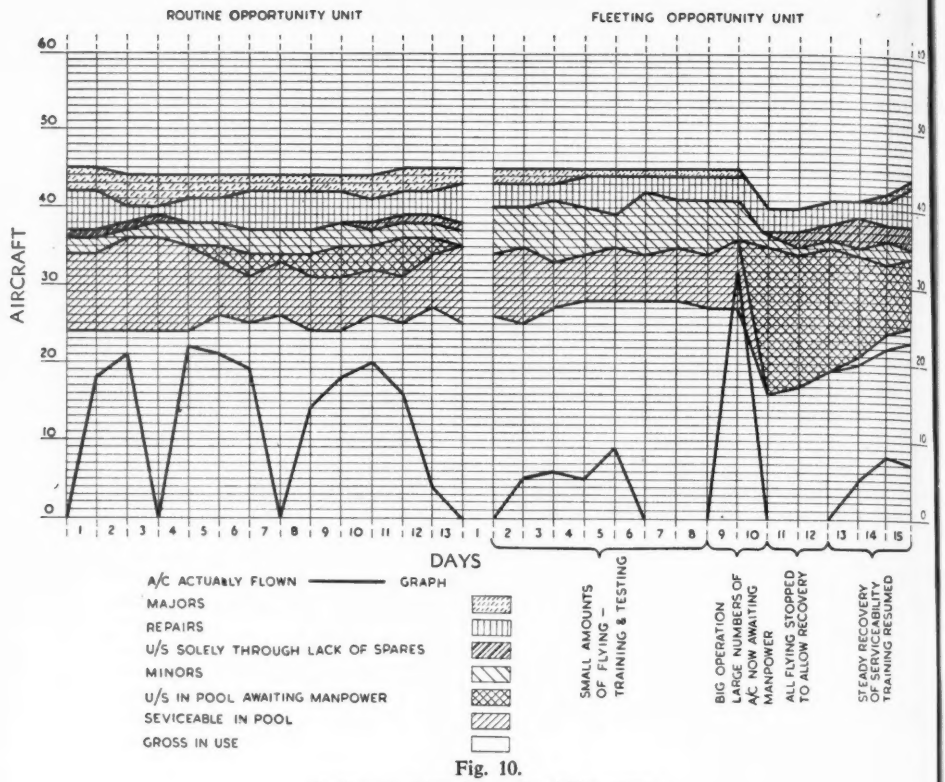


Fig. 10.
Section 4: Aircraft serviceability chart.

3.4. Transport operations

Air Transport operations present their own peculiar features which affect the opportunity pattern. For regular services, aircraft are expected to depart to a daily or weekly schedule and spend a considerable time away from the home base where the bulk of the servicing work is done. Therefore, when planning this type of operation it is necessary to dovetail the departure schedule and the servicing requirements (Fig. 5). For special air support operations the pattern is similar to the bomber and fighter patterns.

3.5. Flying training

In training units where the flow of pupils is fairly constant, weather is often the only disturbing factor. The effect of the weather on the opportunity pattern can be estimated from a study of meteorological statistics.

3.6. Special operations

When planning special operations of limited duration, the intensity and duration of the effort will usually demand slack periods both before and after the operation to allow aircraft serviceability to be recovered to the required level. This can be calculated from the principles already referred to in connection with Fig. 2. (Operation "Longstop" by Transport Command in 1947 and Operations "Dagger" and "Sunrise"—air and sea exercises—in 1948 are good examples of operations of this nature).

In all the above examples a good idea can be obtained beforehand of the opportunity pattern. This knowledge leads to determinable relations between aircraft and man power requirements and thus greatly facilitates the establishment of priorities in the allocation of resources.

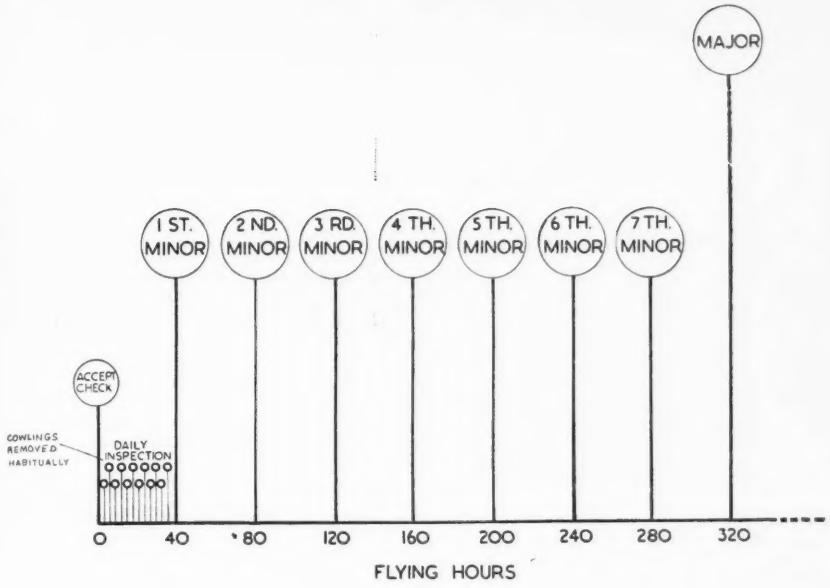


Fig. 11.
Typical minor/major inspection cycle of aircraft (pre-war).

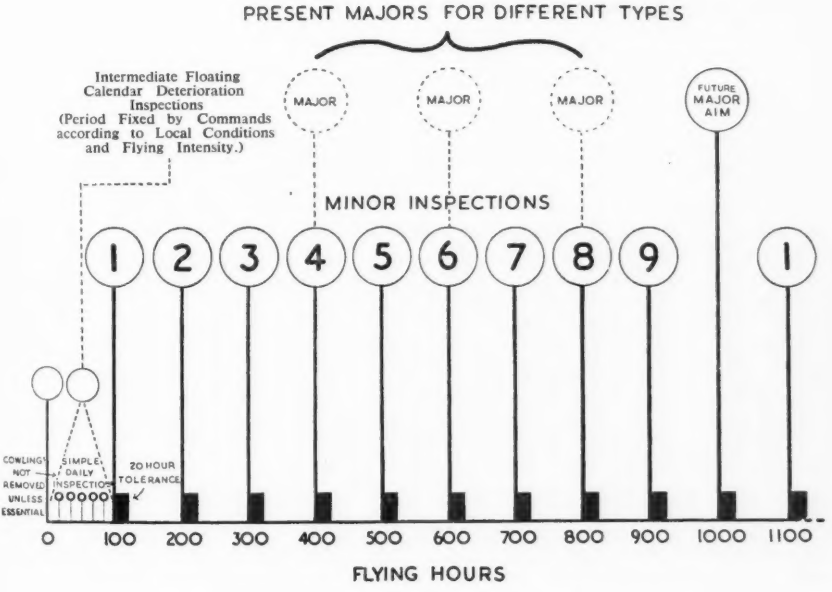


Fig. 12.
Typical minor/major inspection cycle of aircraft (post war).

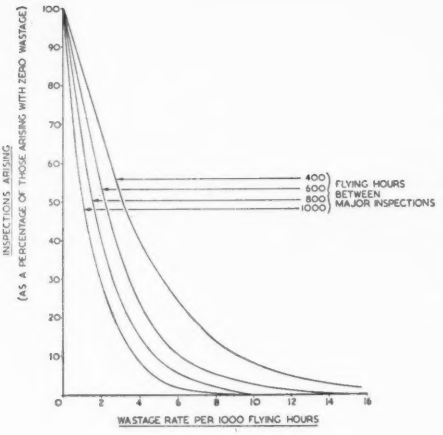


Fig. 13.

Effect of wastage rate on arising of major inspections.

Note—This figure gives a set of curves for wastage rate, *i.e.*, numbers of aircraft lost per 1,000 flying hours against the per cent. major inspections to be expected. This per cent. is on the major inspections which would have arisen with zero wastage, all other conditions unchanged. These curves are correct, assuming:—

(*a*) A large sample of aircraft.
(*b*) Immediate replacement of losses by new aircraft (*i.e.*, zero airframe hours).
(*c*) Uniformity in use of individual aircraft.
(*d*) Wastage rate is independent of airframe hours.

3.7. Insurance

In the preparation of any plan provision must be made for contingencies. The stored strategic resources of the Royal Air Force are held to meet major emergencies, whereas minor contingencies and deviations from the forecast opportunity pattern are provided for by small increases of aircraft or men to the assessment of the resources required to meet their normal commitments, *e.g.* by the provision of an aircraft or labour "pool" in the establishment. These additional resources are in fact an "insurance" and a premium has to be paid in aircraft or men, or both. This "premium" may be reduced by providing some latitude to servicing cycles which has the effect of temporarily reducing the number of unserviceable aircraft. To insure to a fair and reasonable degree is sound policy but to over-insure results in a prohibitive premium which is disproportionate to the risks which are being guarded against.

3.8. Morale factor

Because of the R.A.F.'s incalculable asset of determination and leadership, a much greater effort than that planned for may be attained when necessary. This inherent flexibility allows a Unit to rise to an emergency with smoothness and efficiency. Hence, when in doubt of the precise amount of insurance needed for each task, the knowledge of this "morale" factor enables the planner to avoid paying an unnecessarily high premium in resources. Good leadership and capable management are, therefore, of intangible but great importance to economy.

3.9. Seasonal fluctuations

In certain parts of the world it may be necessary to allow for seasonal influences, since there may be periods for example, during the monsoon, when opportunity would be low, but servicing work could be continued steadily. During the better seasons there may be high opportunities for effort and a good deal can be done in anticipating the servicing programme during the bad weather season, thus storing up potential effort which may be worked off in the good season. The reverse, however, may be required for a flying training task demanding a constant output of trained air crews. In this case more serviceable aircraft would be required during the reduced flying opportunities in winter, because of shorter daylight and bad weather, as illustrated by Fig. 6. Although we cannot plan the weather, it is at least possible to plan in sympathy with its trends, or better still, reduce its importance by providing better navigational aids to flying.

4. PLANNED SERVICING

The wide fluctuations and varying demands of flying in the Royal Air Force which I have indicated, have a direct effect on the servicing to support it, in effect producing too much work at one time and too little at other times for reasonable economy of servicing man power; only careful planning and control can prevent the occurrence of a series of servicing crises. The main object of "planned servicing," therefore, is to plan and control servicing work in a smooth flow to obtain the most economical employment of servicing men compatible with quick turn-round of aircraft

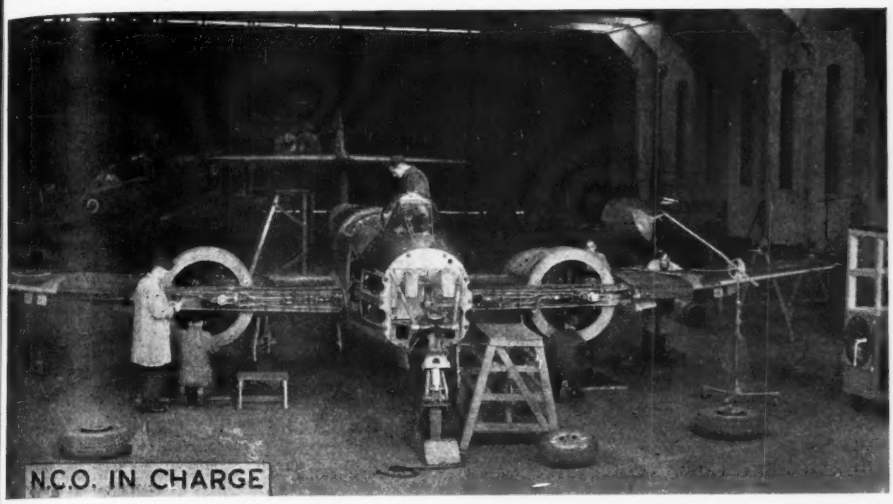


Fig. 14.
Planned inspection of a Meteor fighter, by an inspection team of 15 tradesmen.

for flying operations. (Reverting back for a moment to Fig. 3, the aim is to balance a "constant flow machine" to a "fluctuating flow machine.")

The use of the aircraft "pool" has already been mentioned as a means of meeting uneven demands for serviceable aircraft to increase the flying effort when the weather or operational opportunities permit. The size of the aircraft "pool" is governed by the expected fluctuations in the opportunity pattern. If these aircraft are serviceable, they yield the increased flying effort when required. When they are unserviceable they can be worked on during periods of low flying effort, thus storing up potential flying hours to cater for sudden demands and also providing useful work for otherwise idle men.

4.1. Routine Servicing

The routine servicing, that is, periodic inspections of aircraft, is predictable

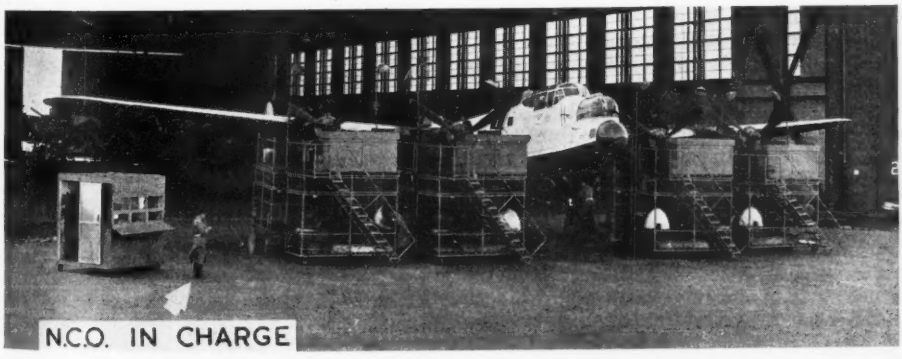


Fig. 15.
Planned inspection of a Lancaster bomber, by an inspection team of 33 tradesmen.

Fig. 16.
Cockpit.
An example of confined space and inaccessibility for aircraft servicing, component replacement and functional testing.

according to the flying task. This can be plotted for a period as shown in Fig. 7. This shows a monthly flying task of 2,800 flying hours requiring a planned average of 100 flying hours a day, which in practice varied from nil hours to about 200 hours in a day because of weather and "week-end" effects, shown by the thick line. In order to support the amount of flying, 56 periodic aircraft inspections (on a fifty hour cycle) were required. If the average turn-round time for each inspection is two days, four aircraft must be continually under inspection by four inspection gangs or teams of tradesmen to produce a constant output of two aircraft a day. Failure to complete even one inspection is a loss of 50 potential flying hours. The turn-round time for each inspection is, therefore, very important. Such rigidity cannot of course be maintained in practice, inevitably hold-ups will occur which must be compensated for by intelligent control of the aircraft and labour "pools."

4.2. Irregular servicing

It is also necessary to consider the repairs, component changes, modifications and so on, and the separate component servicing. They may be referred to as the "unpredictables" which are taken care of by the provision of a labour "pool" known as a "*repair and rectification team,*" which is established according to the estimated arisings of repairs given by statistics. This labour "pool," if it is correctly calculated, is never idle, but may be employed on an excess of repairs at one time and at another time (when repairs and modifications are low) on servicing components which have been replaced. Spare work or spare serviceability can thus be stored up to damp out the fluctuations of recurring defects of components.

The general disposition of a unit's second line servicing personnel is shown in Fig. 8. The repair and rectification team, shown as the "labour pool," floats between the inspection teams, the repairs and the

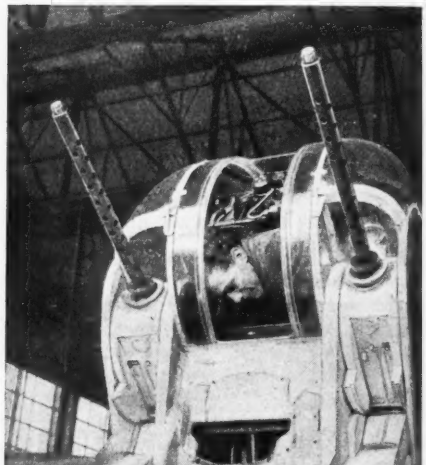
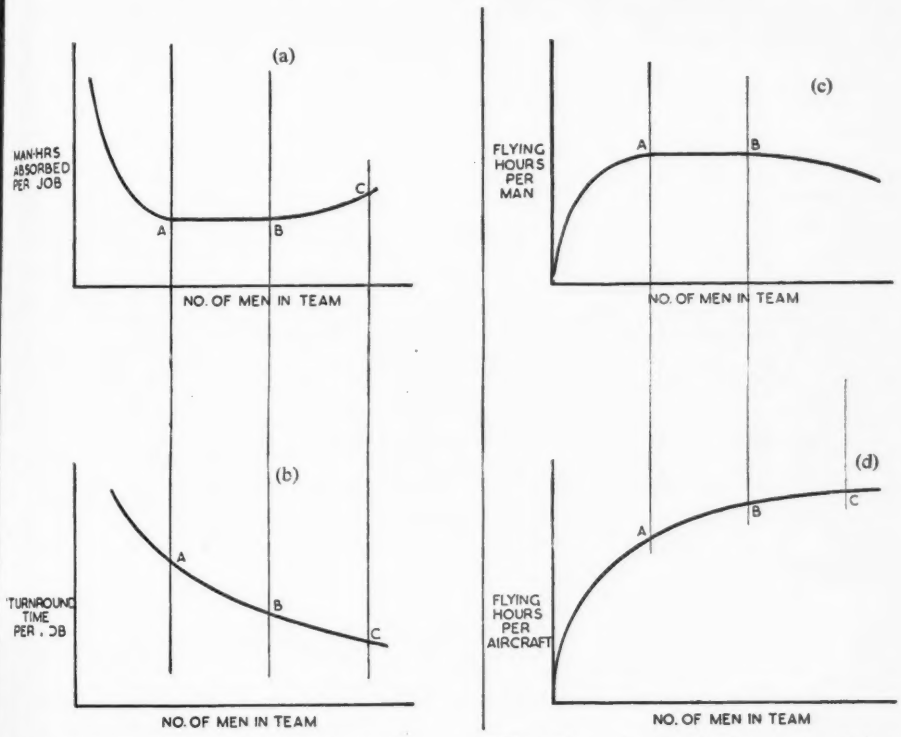


Fig. 17.
Gun turret.
An example of confined space and inaccessibility for aircraft servicing, re-arming and functional testing.



Effect of team-size on working efficiency and turn-round time.

Effect of team size on flying hours per servicing man and per aircraft.

Fig. 18.

Note—
A is the best compromise for small units.
B is the best compromise for large units.
C is the most economic in aircraft.

component bays wherever the servicing load is greatest. The first line servicing personnel are separately established according to the number of aircraft in use, the estimated amount of petty unserviceability (obtained from statistics) and the average length of sorties which affects the amount of aircraft between flight-servicing, refuelling and stand-by time.

4.3. Stagger Charts

One of the most important charts for ensuring an even load of servicing work is the "stagger chart" on which routine servicing work can be plotted, predicted and controlled. The one illustrated in Fig. 9 shows the minor inspections of bomber aircraft arranged horizontally with the respective aircraft vertically. If the arisings of inspections are perfectly staggered from a common datum point (*e.g.* the last major inspection), a straight diagonal line will result at any particular time. The stagger line can then be controlled in sympathy with flying effort, for example, if the flying effort is pulsating, as was found in long-range bomber squadrons whose operations against Germany were regulated to a large extent by the phase of the moon. This is indicated by the lower part of the chart. To ensure the maximum serviceability of aircraft during the operating periods, flying potential was built up by concentrating on the inspections during the non-operating phase,

thereby bending the stagger line to give a credit balance of potential flying hours. After the operations a debit line would result which could be worked off while the demand for serviceable aircraft was low.

Similar stagger charts are used for power plant, component changes and a variety of other routine jobs in order to prevent sudden overloads in any particular department of the servicing organisation.

4.4. Serviceability Charts

A general picture of the relative amount of servicing and average state of a unit's aircraft is given in Fig. 10 as a typical example. This shows that a number of aircraft are constantly unserviceable for various reasons while a number of serviceable aircraft are rarely flown. To improve this picture from the economic point of view, many die-hard traditional conceptions of servicing and usages of aircraft in the R.A.F. have had to be abandoned and replaced by more efficient methods. This has been accomplished by further research, described as "Rationalisation of Methods."

5. RATIONALISATION OF METHODS

In the past the servicing cycle of an aircraft was fixed arbitrarily from general experience of the type. Situations often

Sheet No. 40 A.P. 2979A. Vol. IV. Ft. 8. AIRFRAME.

BASE SERVICING
HASTINGS C. Mk. I. AIRCRAFT
AIRFRAME MAN "B."

Item No.	Description of Operation.	Item Time	Prog Time
	Throughout the Servicing, pay attention to bonding and rectify where necessary. For lubrication where oil is used, use oil, lubricating, anti-freezing, (34A/87), and where grease is used, use grease, low temperature (34A/174), unless otherwise stated.		
1.	Assist Man "A" to position ground equipment.	.15	.15
2.	Refer to Panel Diagram and remove the following panels:— T. 31, 33, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54. P. 36, 62, 75, 76, 77, 78. S. 36, 62, 75, 76, 77, 78. Place loose panels on airframe equipment rack and screws in cloth bags and attach to appropriate panel.	.50	1 05
3.	Servicing Hatch. (*a*) Drain the pneumatic system oil and water trap. (*b*) Drain the air filter. (*c*) Recharge the pneumatic system to 200 lb./sq. in. Note the inflation pressure for leak test in Item 9.	.15	1.20

Sheet No. 40 (*Continued*)

BASE SERVICING

Item No.	Description of Operation.	Item Time	Prog Time
4.	Check the pressures of the following:— (*a*) Emergency air bottle 1,400 (plus 50, minus 200) lb./sq. in. (*b*) Flap accumulator 950 (plus 20, minus 20) lb./sq. in. (*c*) Power accumulator 1,600 (plus 0, minus 100) lb./sq. in., with zero pressure in system.	.05	1.25
5.	Remove the hydraulic purolator filter and fit a serviced component. Relock unions.	.20	1.45
6.	Examine the hydraulic header tank for leaks. With flaps and undercarriage down and with zero hydraulic pressure in power accumulators, check the fluid level and replenish header tank as necessary with fluid, hydraulic (34A/159).	.10	1.55
7.	Generally check for hydraulic leaks and examine the heater pipes, particularly below the header tank, for damage and oil soakage.	.05	2.00
8.	Examine the rudder and elevator push-pull tubes for security of tube joints. Lightly lubricate the tubes where they pass through guides and		

(*Continued*)

Fig. 19.

Specimen work sheet for airframe inspection on Hastings aircraft.

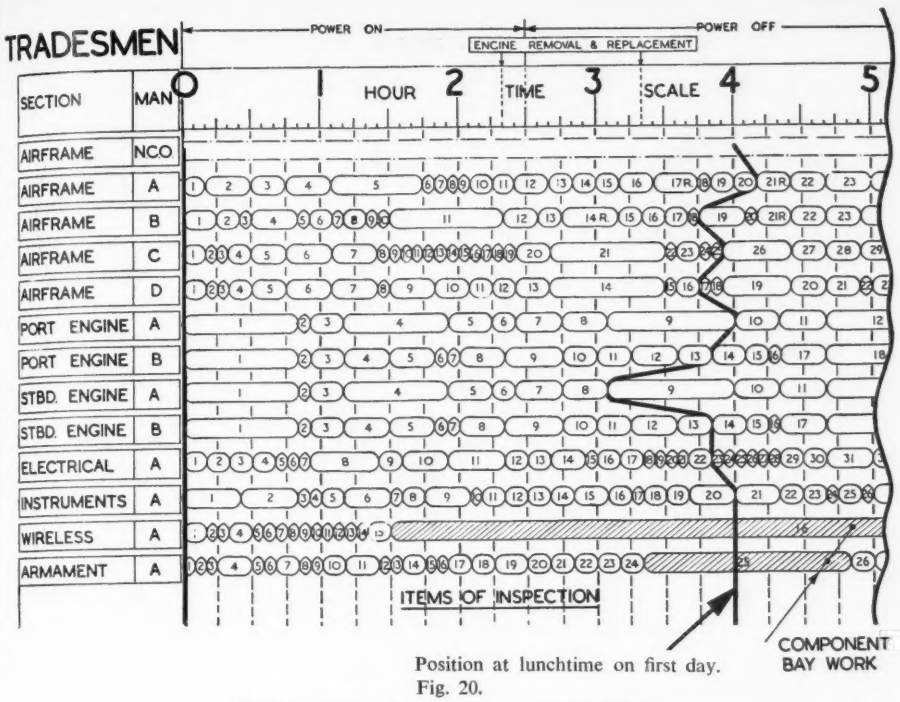


Fig. 20.

Meteor minor inspection work progress chart.
Total turn round time, 14 hours; inspection time, 9 hours.

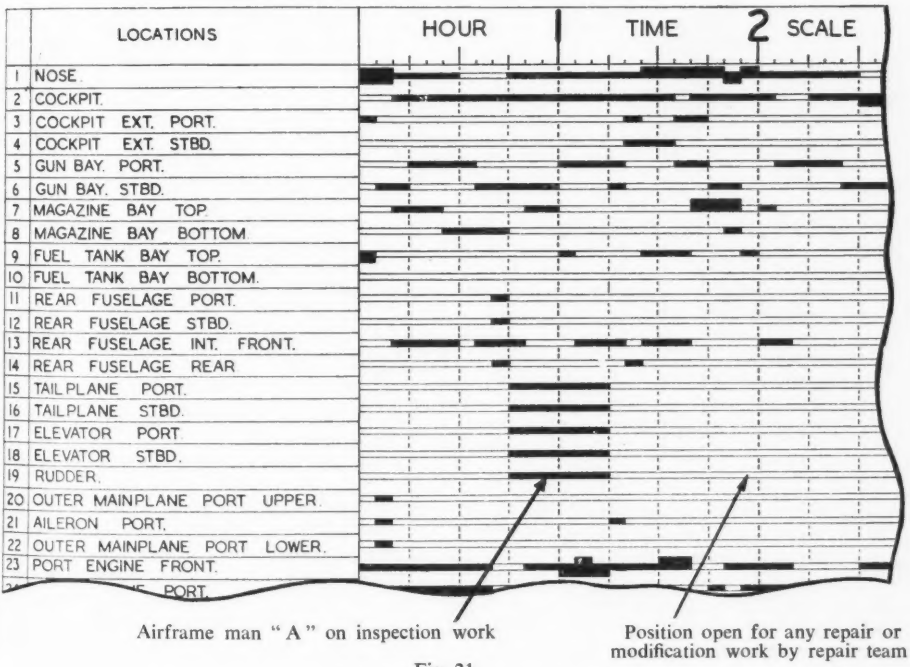


Fig. 21.

Meteor minor inspection disposition chart.

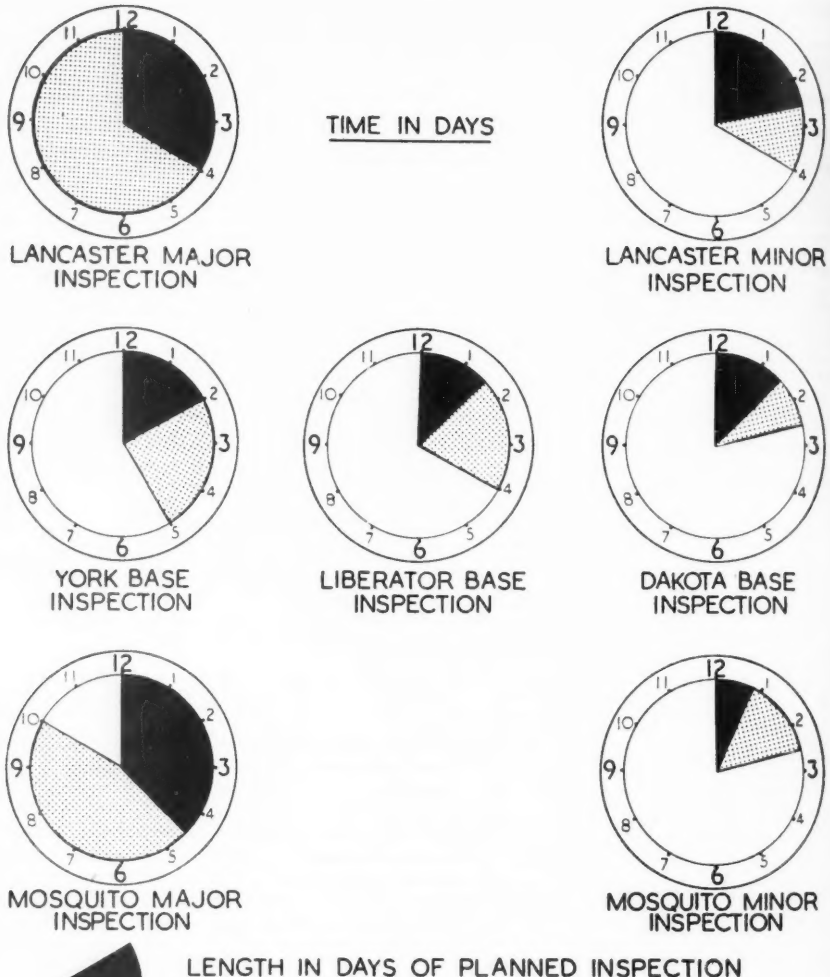


Fig. 22.
Diagrammatic representation of some typical inspection turn-round times before and after the application of planned inspection technique.

arose where different Commands using the same type of aircraft were operating them to different cycles; also, the amount of servicing work for each period varied considerably. These differences affected the establishments of aircraft and men for identical jobs, while no one knew with any degree of accuracy how much work was involved or how long it should take. Major inspections, for example, on some particular aircraft took as long as a month at some units, whereas others might take half that time. It depended on too many unknown quantities, what tradesmen were available

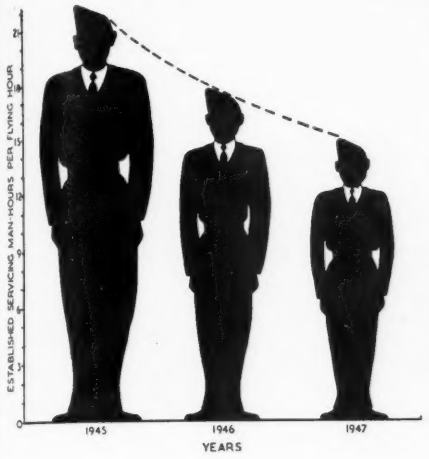


Fig. 23.

Economy of servicing establishment effected by the introduction of planned inspection system (F.E.A. Servicing Echelon).

at the time, what experience they had of the type of aircraft, what tools and equipment were available or what spares were to hand. Here was a large unexplored field for investigation and rationalisation. Some of the problems and the solutions found were as follows.

5.1. Servicing cycles

It will be appreciated that routine servicing of aircraft is necessary to combat two kinds of deterioration, wear and tear caused by usage and corrosion caused by climatic conditions. Normally, wear and tear inspections generally automatically cover inspection for corrosion at the same time, therefore, if the flying intensity of the aircraft is high enough, separate inspections for corrosion are unnecessary. On the other hand if flying intensity is low, the state of the aircraft must be safeguarded by ensuring that an inspection is made within the maximum permissible periods of calendar time that corrosion can occur. If these two kinds of inspection cycles cannot be properly located in the life of an aircraft, they will have serious repercussions on the servicing costs. Because the flying intensity of aircraft in the R.A.F. varies considerably, and flying takes place under varying climatic conditions, two factors are of primary importance, *the general reliability of the aeroplane and its resistance to climatic conditions.*

Formerly the R.A.F. relied on inspections for wear and tear varying from 40 to 80 flying hours between each inspection, which followed a traditional cycle of seven minor inspections to one major inspection as shown in Fig. 11. Climatic deterioration was taken care of during comparatively lengthy daily inspections, during which all the cowlings were invariably removed for interior inspection of the aircraft on the worthy principle that "it is better to be safe than sorry!" Hence there was a tendency to over-inspect and disturb the aircraft and reduce the available flying time, until eventually the daily servicing man-hour per flying hour cost became prohibitive.

Figure 12 shows the present tendency towards a standard 100 flying hour cycle for minor inspections of all aircraft, with a tolerance on each period to provide flexibility of operation.

The major cycle is determined by the general reliability of each type of aircraft which, it is hoped, can be universally extended to 1,000 flying hours if manufacturers can design major components to last this period. This has a dual effect on servicing economy reflected by Fig. 13; as military aircraft, not unnaturally, are prone to high wastage rates and early

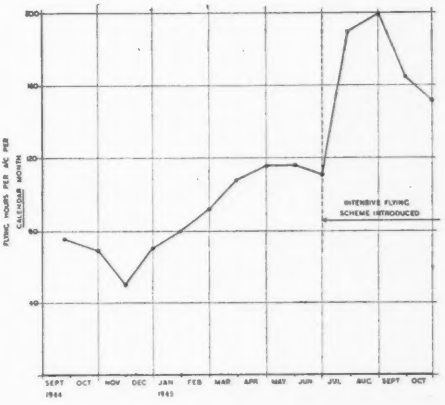


Fig. 24.

Trend of flying intensity before and after introduction of the planned servicing scheme. York aircraft, 511 Squadron, R.A.F. Lyneham September 1944—October 1945.

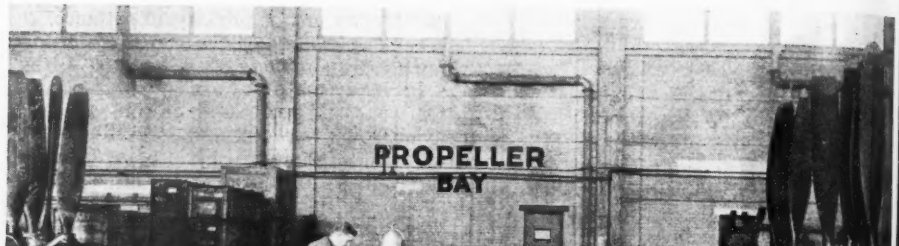


Fig. 25.
Component servicing.
Propellers being serviced independently of the aircraft, according to a policy of "repair by replacement."

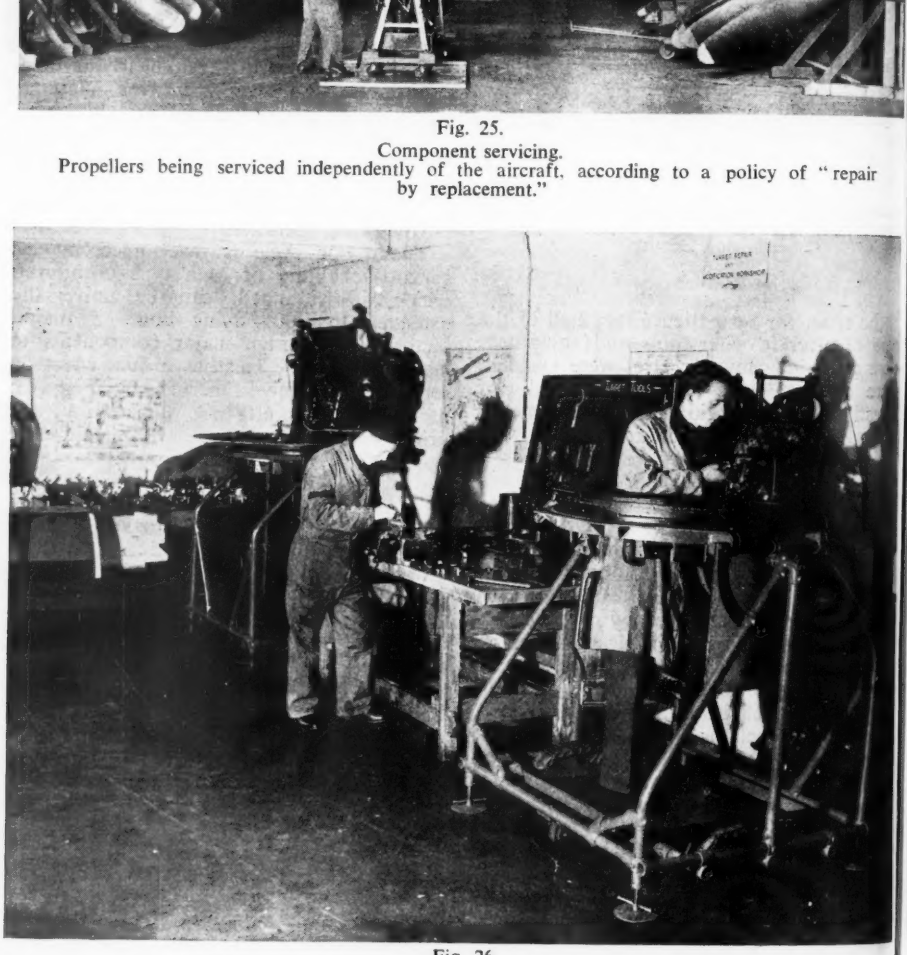


Fig. 26.
Component servicing.
Gun turrets removed from the aircraft being serviced in a turret shop, where all facilities are provided.

obsolescence, which affect the anticipated number of major inspections and therefore, the servicing costs. Reverting back to Fig. 12 it can be seen that in order to ensure that aircraft with low flying intensities (taking many weeks to reach a minor inspection) are thoroughly inspected for corrosion or deterioration, a "movable" calendar inspection has been introduced which can be done at any determinable calendar periods, depending on local conditions of usage, intensity of flying, proximity to the sea, humidity and temperature, and the like.

The daily inspections have been simplified and reduced, based on the principle that the aircraft is considered serviceable unless reported otherwise by the flying crew. The daily inspections therefore depend to a large extend on correctly reported defects by flying crews.

5.2. Inspection Schedules

While attempting to obtain the most economic inspection cycle, it became necessary to examine the inspection schedules to eliminate unnecessary items of inspection or regroup or upgrade others and plan the individual jobs in a correct sequence. Planning the schedules involves an element of time and motion study and careful co-ordination between the different tradesmen employed simultaneously on the inspection (shown by Figs. 14 and 15), in order to avoid congestion and interference in such confined places as cockpits and turrets, which are inherently difficult and inaccessible places for servicing. Figs. 16 and 17 show typical examples of such places.

Planned inspection requires balanced "inspection teams" or gangs of tradesmen which are a complementary study; the ultimate aim being the most practical and economical turn-round time for inspections. In determining the size of the inspection team there are two yardsticks of economy, (*a*) the flying hours produced per month per tradesman in the team, and (*b*) the flying hours per month per aircraft. The economics of inspection team size are

Fig. 27.
Component servicing.
Sparking plugs being serviced by semi-skilled workmen.

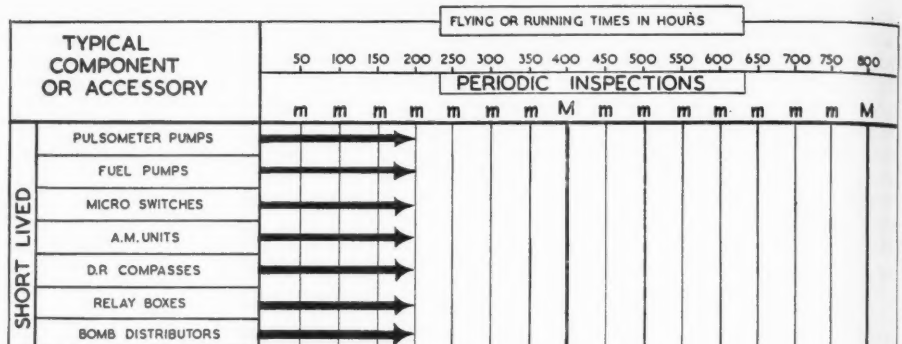


Fig. 28.
Component lives.

shown in Fig. 18. Often a compromise has to be made to adjust the team size to the highest common denominator that will fit into the Unit establishments, which are governed by operational requirements. These establishments may sometimes be so small that the desired team size cannot be obtained from them, in which case a smaller inspection team has to be accepted, despite the slightly higher man-hour cost or increased turn-round time for inspections.

Reverting back to the build-up of the schedule, the individual jobs of each tradesman are tabulated on separate work cards, a specimen of which is shown in Fig. 19. These detail the jobs, the order, the approximate time for each item and the tools and equipment required. Omnibus phrases such as "inspect the main-planes" are avoided, as such phrases can be differently interpretated by different tradesmen, according to their conscience. At the same time any tendency to make the tradesman's work a purely repetitive process, as in a factory or like rifle drill, is undesirable, because as Air Marshal Cochrane has so aptly remarked, "we want a tradesman to have a roving eye actuated by an intelligent mind, not a mechanical one!"

The individual work of the team is progressed, co-ordinated and controlled by the N.C.O. in charge of the inspection team, with the aid of two charts, one a work progress chart (Fig. 20) on which he can

plot the progress of all the jobs on the time scale for the inspection. A set of coloured pins is used for this purpose which immediately reveals any hold-up in the inspection so that he can take appropriate action. If any major defect arises which requires additional men, he can immediately call for assistance from the repair and rectification team, the mobile "labour pool" already mentioned which is established to take care of these incidental jobs.

The second chart is a disposition chart (Fig. 21) which indicates what parts of the aircraft are being inspected at different times, from which the N.C.O. can decide the best time to fit in any additional work (indicated by the blank spaces), such as modifications and repairs.

Each man signs for his own work on an individual record card for each item of the inspection, which is finally countersigned by the tradesman's supervisory N.C.O. in the team, who is responsible for inspecting each tradesman's work and for ensuring that its quality is up to standard.

The economies that have been achieved by this system of "planned inspection" are considerable. Some comparisons between the former turn-round times and the new planned times are shown in Fig. 22 and the savings in man-power in Fig. 23, and the effect on flying intensity in Fig. 24.

5.3. Component Servicing

Further improvement in the turn-round times for servicing operations has been gained by a system of "*repair by replacement*," whereby unserviceable components are removed from the aircraft and serviced

UNIT:- RAF RISLEY — **AIRCRAFT STATE BOARD** — DATE:- 28/7/47

CODE	AIRCRAFT Nº	STATE	FLYING HOURS CURRENT CYCLE 10	20	30	40	50	60	70	80	90	100	POOL U/S	REASON FOR U/S	DATE U/S	TAKEN OVER A/C	SERVICING PROGRESS 25%	50%	75%	100%	GROUND RUN	SNAGS	AIR TEST	'S' POOL	DATE 'S'
A	JF210	S	✚																						24/7
B	JF 272	U/S											✚	m	28/7										20/7
C	JF 921	S			✚																				28/7
D	JF 922	S											✚	m	27/7										8/7
E	JF 321	U/S					✚																		18/7
F	JF 689	U/S												M	25/7	1		✚							7/7
G	JF 714	S							✚																5/7
H	JF 471	U/S												m	29/7	2					✚				5/7
J	JF 707	S									✚														27/7
K	JF 709	S												m	24/7	1								✚	26/7
L	JF 710	U/S												ENG & MOD	25/7	C/S			✚						

SCHEDULED SERVICES AIRCRAFT POOL	AIRCRAFT Nº	STATE	ROUTE CYCLE: TRANSPORT AIRCRAFT U.K.-C.B	C.B.-LYDDA	LYDDA-M'PUR	M'PUR-LYDDA	C.B.-U.K.	U.K.-C.B	LYDDA-M'PUR	M'PUR-LYDDA	LYDDA-C.B.	C.B.-U.K.
35	JF 120	U/S										✚
37	JF 273	S			✚							
39	JF 922	U/S								✚		
41	JF 690	S	✚									
43	JF 710	S										
45	JF 908	S										

35	JF 120	U/S	B	21/7	3
37	JF 273	S			
39	JF 922	U/S	ENG	23/7	
41	JF 690	S			
43	JF 710	S			
45	JF 908	S	B	18/7	3

GROSS-IN-USE AIRCRAFT INCLUDING TEMPORARY UNSERVICEABILITY

AIRCRAFT UNDERGOING SERVICING 'POOL' AIRCRAFT

NOTES:- ✚ BLACK = 'S' ✚ RED = 'U/S' ✚ YELLOW = AOG (AWAITING SPARES) ✚ GREEN = CAT A/C

m = MINOR INSPECTION, M = MAJOR " , B = BASE " , X = ADDITIONAL ITEMS TO BASIC INSPECTION

ENG = ENGINE CHANGE, MOD = MODIFICATION WORK, REP = REPAIR, ACC = ACCEPTANCE INSPECTION, S.I = SPECIAL INSPECTION

Fig. 29.

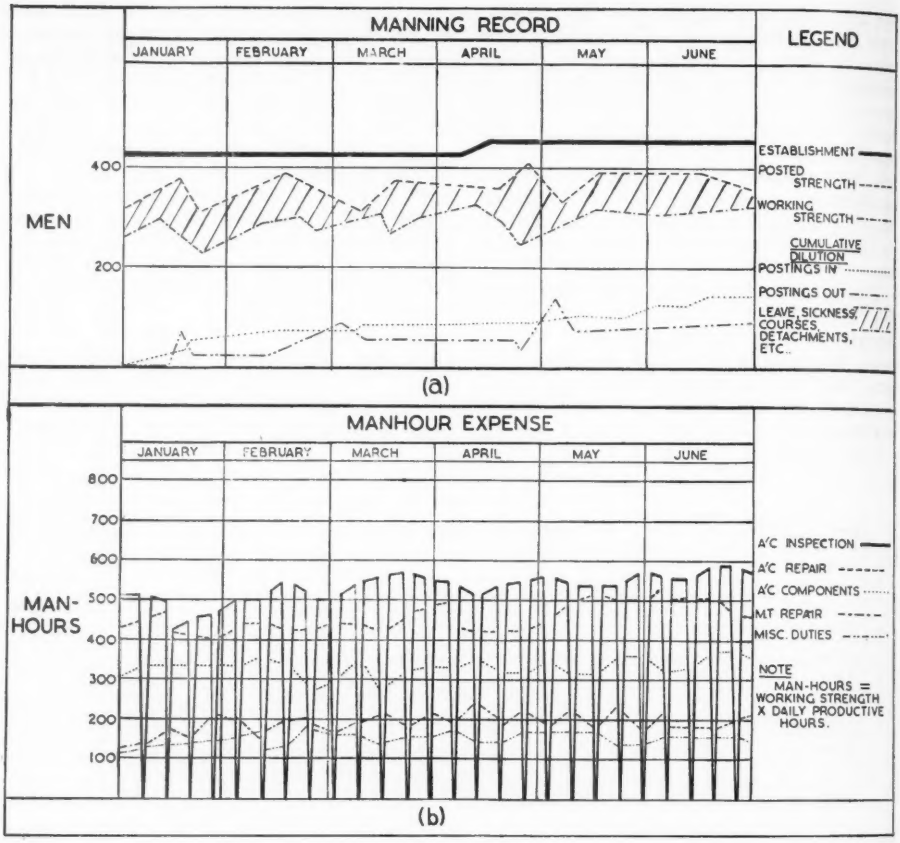


Fig. 30.
Man power record charts.

centrally in component bays. This accumulation of component work can then be planned, timed and sequenced in a logical order in a similar way to that already described for the aircraft. "Repair by replacement" offers many other advantages, such as improved standards of work in a workshop provided with all facilities, full employment of semi-skilled tradesmen on repetitive processes, economy of fully skilled tradesmen, reduced hangarage (by virtue of reduced aircraft turn-round time) and improved record keeping. Illustrations of this kind of work are shown in Figs. 25, 26 and 27.

Accurate record keeping is necessary to keep track of defective components, and to determine from resulting statistics of failure rates, the most economic lives of components in order to fit them into the aircraft inspection cycles. Fig. 28 shows the effect of this grouping of different component lives, which aims at synchronising the individual component replacement at a convenient aircraft inspection, despite the possible loss of some running or flying hours in each component. It should be possible, in future, to collect sufficient data from these records to show which components are a heavy maintenance liability to the Service.

5.4. Technical control

The co-ordination of the many aircraft servicing activities requires a central control

section. This is a small overhead amply compensated by the large economies that are achieved in other directions. The purpose of the technical control section is to progress and control all servicing operations in sympathy with flying operations, deploy servicing personnel to the best advantage and maintain accurate records of servicing operations, defects, flying hours and man-hours, and so on, to enable statistics to be compiled for analysis, without which the checking of comparative effort and cost would be impossible. Figs. 29 and 30 (together with Figs. 7, 8, 9, 10 and 28) are typical of some of the control charts to be found in a technical control room to control the progress of the flying and servicing tasks.

The many other activities of rationalisation can be summed up as follows:—

(*a*) Application of up-to-date techniques and production engineering methods to aircraft servicing.

(*b*) Studying the servicing necessary from the point of view of the design of the aircraft.

(*c*) Studying the deterioration of aircraft under different conditions and in various operational roles.

(*d*) Studying the details of defects and accidents caused by technical failures.

(*e*) Logical control of the contents of aircraft servicing schedules and of servicing cycles.

(*f*) Detail planning of individual jobs to ensure maximum economy of man-power and shortest aircraft turn-round times.

(*g*) A statistical study of the man-power requirements, by trades, for various servicing operations in order to arrive at sound data for calculating servicing personnel establishments.

(*h*) Continual development and improvement of tools and servicing equipment in order to reduce man-hours and fatigue.

(*i*) Centralisation of component servicing to facilitate repair work and to cut down turn-round time of aircraft servicing.

(*j*) Development of a sound and foolproof system of technical documentation.

(*k*) Technical control of all aircraft throughout the flying and servicing cycle.

PART II

6. MAINTENANCE DESIGN

In the course of investigating the foregoing features having a bearing on the economical use of aircraft and man-power, it became abundantly clear that it was essential when designing aircraft for the Royal Air Force to have in mind the conditions under which they operate, the number and quality of men, and the degree of skill and knowledge, required to service the aircraft. *Economy of man-power and aircraft for training and operations, can clearly be increased if the servicing hours demanded for individual jobs can be reduced.*

Therefore I now want to suggest how the aircraft designer can help to improve economy in many ways.

The investigations I have described have brought forth many criticisms of aircraft design from tradesmen whose work is made unnecessarily difficult because servicing problems have not been given sufficient attention during the design stage. Tradesmen complain of the inaccessibility of items which need frequent attention (Figs. 31 and

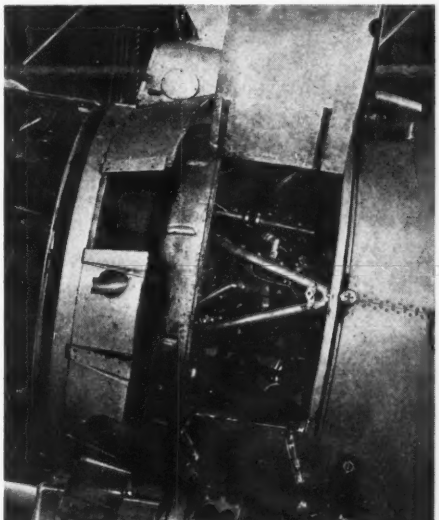


Fig. 31.
Inaccessibility.
A good example of congestion and inaccessibility of components behind the engine.

Fig. 32.
Inaccessibility.

The electrical fuse panel and junction boxes of this aircraft are behind panels in an inaccessible position underneath the flight engineer's operating table and instrument panel. The seat and the covering panel have to be removed and approximately one man-hour is expended to change a fuse.

32 are typical examples); of badly designed cowlings which distort and of inspection panels difficult to remove and replace (Fig. 33 shows a particularly bad one); of flimsy attachments and a multitude of detail nuisances, such as that shown in Fig. 34. They claim, rightly or wrongly, that some designers have ignored the adverse conditions under which servicing, particularly in the field, must be performed. In addition to the examples given in Appendix D of indifferent design features found in aircraft in current Service use, the following are some general criticisms and queries.

6.1. Nuts and bolts

Small components, especially those of the electrical and instrument systems, are often secured to bulkheads or panels by small nuts and bolts. Although the bolts are generally accessible, often the nuts are not, consequently the removal of such components is laborious, since great care must be taken not to lose the nuts in the process. Is it not possible to use anchor nuts behind blind panels and bulkheads, which would make removal and replacement so much easier and less tedious for the tradesman, probably working with cold fingers out in the open in winter? This may appear to be

a small point, but the sum total of this work for many components, represents a large number of man-hours spent and aircraft flying hours lost. Fig. 35 shows one method for easy access to panels carrying instruments.

6.2. Fuel systems

Pumps and fuel pressure warning lights are usually fitted in such a manner that all fuel must be drained before they can be removed for servicing. Would it not be possible, at the cost of a few ounces in weight, to fit isolating cocks or valves so that pumps could be removed without the necessity to drain the tanks?

6.3. Oil systems

The draining of oil often requires the full time attention of a tradesman while the operation is performed, and frequently, the diameter of drain pipes is so small that drainage takes a considerable time, even when the oil is hot. In some cases the position of the drain pipe is such that the oil blows all over the aircraft if the operation is attempted in the open air; a great nuisance on a sandy airfield. A good design is illustrated by Fig. 36.

6.4. Cowlings

Fairings and cowlings are generally difficult to remove and are rarely interchangeable between aircraft of the same type, therefore, when originals become badly damaged it is necessary to drill and "tailor-make" the new coverings for the aircraft. This operation often involves work on surfaces with double curvatures and requires special skill and experience which are difficult to

Fig. 33.

Laborious servicing.

The stall-warning device in the mainplane leading edge of this aircraft has an inspection panel secured with 110 screws, which screw into poorly designed anchor-nuts. If the last anchor-nut should fail during replacement of the panel, the whole process (approximately 11 man-hours) for removal and replacement of the panel must be repeated.

Fig. 34.
A servicing nuisance.

The narrow communicating door between the flight deck and main cabin of this aircraft has no catch to keep it open, and is a constant nuisance during servicing operations unless it is removed altogether. This type of door should be designed to slide out of the way.

obtain, apart from the cost in man-hours. Is it not possible to reverse the process of jigging fitting points, to improve interchangeability, by jig drilling panels first and the structural members afterwards to suit the panels? Alternatively, hinged panels are often a solution to this problem as shown in Figs. 37 and 38, examples of excellently designed engine cowlings which speak for themselves.

6.5. Charging points

Hydraulic, pneumatic, nitrogen, and other charging points are sometimes scattered all over the aircraft. This is undesirable for rapid servicing and functional testing when many different panels have to be removed. That some designers are conscious of this, apart from structural considerations, is evident from the excellent positioning of the servicing points shown in Figs. 39 and 40.

6.6. Installation of radio equipment

Radio and power sets are generally difficult to remove and replace because of a combination of the equipments' weight, size, type of fitment and accessibility. Some standardisation of mountings and connections is necessary, particularly for the same type of equipment, while it might be possible to build up future equipments in sectional units of miniature size. Where possible, all fittings and locking devices should be of the "quick release" pattern. A good example of what can be done is shown in Fig. 41.

6.7. Standardisation

The benefits to be gained by standardisation of common parts are so obvious that they should need no amplification, although we continue to encounter many difficulties in this respect. For example, several types of hydraulic fluids have to be used in the Service because they are specified by the manufacturer. This complicates the supply problem and is a constant menace, as inexperienced personnel are liable to use incorrect fluids and so ruin the glands. In other cases different size lubricating nipples are fitted to an aircraft to perform the same function, which multiplies the number of lubricating tools.

I do not want to digress too far along these lines as there are innumerable examples and probably many good reasons for them, but I must mention the much wider aspects to this problem, for example, in respect of combined operations with our Allies. I think it worth recalling that prior to "D" Day for the invasion of France in June, 1944, I was detailed to investigate the servicing requirements for British and American fighters planned to use the same airfields in harmony during the initial assault. There were only two things common to both tactical air forces, petrol and language!—although there may be slight differences of opinion about the latter—oil and coolant, electric starter plugs and sockets, oxygen and radio equipments and

even ammunition and common nuts and bolts were different. This meant complete duplication of supply pipe lines, with the one exception of petrol which was supplied by the cross Channel pipeline—P.L.U.T.O.

6.8. Modifications

Most servicing and production engineers will agree that modifications, no matter how necessary for the safety of the aircraft or in the interests of progress, are a continual bugbear to be borne with the best possible grace. They often seriously curtail flying and servicing operations and hold up production, and many could have been foreseen in the original design. The benefits to be obtained and the cost of incorporating them should always be carefully weighed. It must be accepted, however, that certain operational modifications to military aircraft will be always necessary to improve their performance, or to obtain a tactical advantage over the enemy by the incorporation of new and improved equipment. There are innumerable examples of this kind of modification, especially during the last war, such as the fitting of armour plate and variable pitch constant speed propellers to our fighters prior to the Battle of Britain, the embodiment of gyro gun-sights, self-sealing fuel tanks, blind navigation and bombing radio equipments, and a host of other new devices. Nevetheless, the design and embodiment of modifications should take into account carefully the maintenance implications. An example of ill-considered modification was the embodiment of S.B.A.

Fig. 35.
Design for easy servicing.
The blind-flying panel of the Martin-Baker fighter aircraft is mounted on a hinged panel which allows access to the back of the instruments and to the compartment behind the panel.

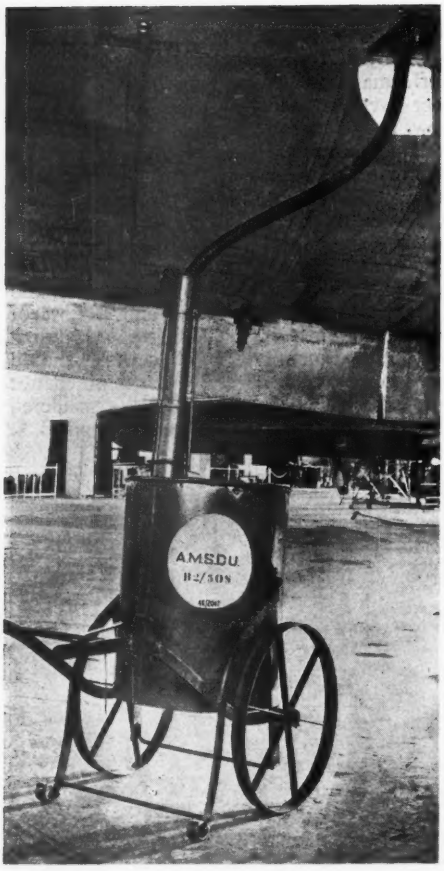


Fig. 36.
Design for easy servicing.
Suitable provision is made on this aircraft for oil draining by a screwed coupling pipe.

equipment in a certain trainer aircraft under the rear cockpit seat. It was necessary to remove the starboard exhaust pipe, side panel and rear cockpit seat before a mechanic could service the equipment. In this case the difficulty could have been eased by the fitting of an easily removable cockpit seat.

6.9. Reliability

Most of my remarks so far have been concerned with servicing difficulties. I should emphasise, however, that in parallel with this aspect of design there will need to be greater efforts by manufacturers to improve the reliability of components. This requirement appears to me to be of paramount importance because accessibility of components in very high speed aircraft is rapidly becoming more difficult to achieve. High speed and the elimination of parasitic drag is forcing ever sterner demands on the already hard-pressed aircraft designer for cleaner profiles for super-sonic flight, which demands the burying of components in such a way that no servicing, or even inspection, should be required for them during long periods of use.

Quite apart from the high servicing cost of unreliable and inaccessible components, there is the disruption to flying operations caused by recurring defects, the resulting low flying intensities which govern aircraft establishments and the heavy cost of spares to be taken into account.

Unfortunately, the number of defects reported by both flying crews and servicing personnel shows there is no room for complacency concerning aircraft reliability. Equipment is constantly reported to be unserviceable after sorties and during inspections for a variety of reasons, which range from engine failures to prematurely discharged accumulators. I do not propose to single out any particular item of equipment or aircraft, as comparison is impossible unless all the circumstances of production, operation and servicing are taken into account. In order to give some idea of the incidence of these defects and their rectification cost in man-hours, I have chosen firstly, two representative but totally different and anonymous aircraft, one a four-engined type, the "F.E.A." (65,000 lb. A.U.W. approx.), and the other a twin-engined aircraft, the "T.E.A." (30,000 lb. A.U.W. approx.), and taken a sample of their reported defects. This sample is shown pictorially in Fig. 42. This summarised analysis is not conclusive, because of the administrative difficulties of accurately reporting all defects and the man-hours expended on their rectification "in the field." But even if this sample is taken as the *minimum* number of defects that occur there is obviously room for much improvement. Secondly, Fig. 43 is a sample of the defect rates for various Service aircraft used for flying training covering a period of 9 months and involving a total of about 150,000 flying hours. This high incidence of defects for all kinds of components at the present time

mocks all attempts to develop an orderly servicing procedure.

I have only attempted to give a few of the general features of design which affect maintenance because many detailed examples have already been discussed in Lieutenant Bowden's papers[1], in subsequent correspondence[2] and in Mr. Kemper's paper[3]. The latter, particularly, in my opinion, is worthy of further study.

1. Lt. T. E. G. BOWDEN. Design for Maintenance. JOURNAL R.Ae.S., March 1947; Maintenance Design Questions, JOURNAL R.Ae.S., August 1948.
2. Correspondence. JOURNAL R.Ae.S., May, June, July 1947; October, November, December, 1948.
3. M. J. KEMPER. Maintenance Difficulties in the Field. JOURNAL R.Ae.S., December 1947.

6.10. SPECIFICATIONS

The faults of maintenance design do not lie entirely with the designer to whom is given the aircraft specification. Examination of a number of specifications revealed a striking lack of prominence to ease of maintenance requirements. A good example was included in a certain specification for a single-engined advanced training aircraft. This document consists of 13 pages, the majority of which are devoted to a detailed description of the performance required and various handling characteristics and the like. The speed is stated within one mile per hour, and similar accuracy is observed in giving other performance requirements. Only two short paragraphs are included on maintenance requirements which are as

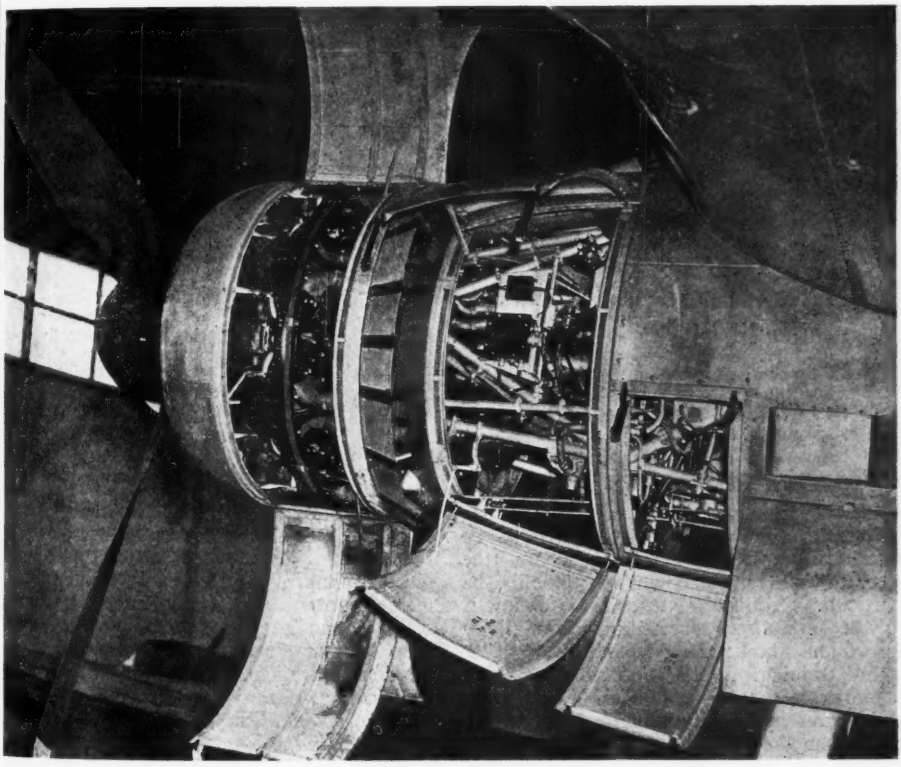


Fig. 37.

Design for easy servicing.

The Hercules power plants of the Hastings R.A.F. transport aircraft have hinged cowlings which can be quickly and easily lifted for engine servicing. There is ample room at the back of the engines, which allows accessories to be easily changed.

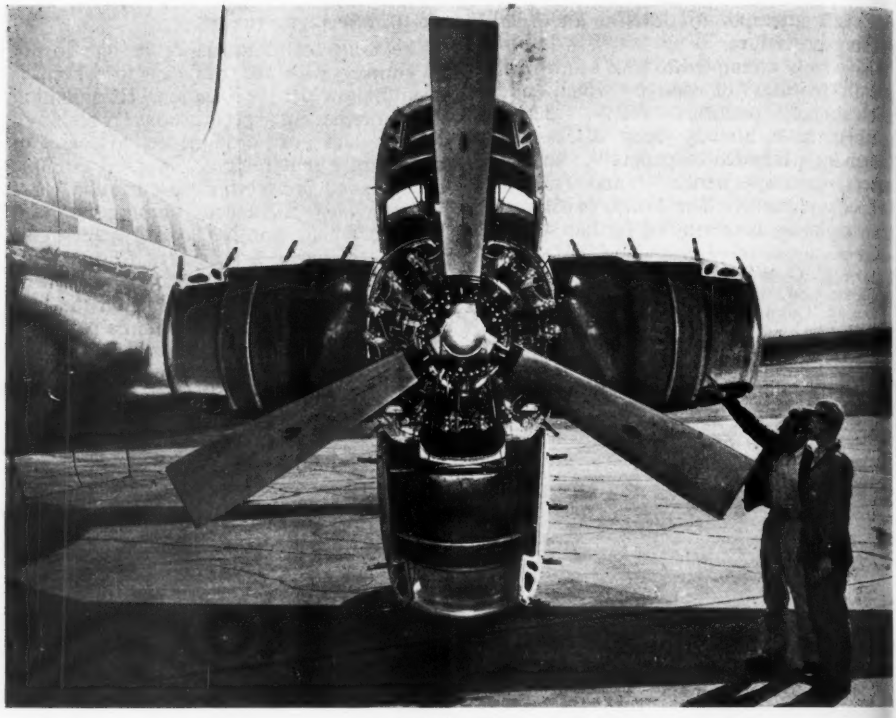


Fig. 38.

Design for ease of servicing.

Each engine on the medium-range Convair Liner has an "orange peel" cowling—a full-cantilever, four-section cowling which can be quickly swung wide open to expose the entire power-plant for inspection or servicing. If desired, any single section can be swung back independently of the others, uncovering only that section of the engine the mechanic wants to work on. The cowling completely encloses the engine, but is not supported by it. Except for a resilient rubber air seal, there is at all times a $\frac{5}{8}$ in. clearance between the cowling and the power plant. Thus the cowling requires no servicing as a result of engine vibration.

follows:—" A high degree of inter-changeability of parts is required; oleo legs, struts, wheels, etc., should, as far as possible, be inter-changeable on either side of the aircraft. Engine cowlings should be particularly robust. Particular attention is to be given to accessibility for daily inspections and servicing operations.

In training aircraft considerable discomfort is experienced during aerobatic instruction by dust falling into the pilot's eyes when the aircraft is inverted. Removable panels are therefore required so that dirt can be easily removed between flights!"

This statement of the maintenance requirements is clearly inadequate. The aircraft designer should be asked to exercise his skill in simplifying and reducing the work of servicing personnel equally as much as in meeting any other requirement of the specification. The specification must not give the impression that maintenance is of little importance. The difficulty of foreseeing the maintenance problems which will arise with new equipment is no justification for ignoring them. *To ignore them may well result in a serious diminution of the striking potential of the Royal Air Force because of the inability to provide the numbers and quality of tradesmen required for servicing and low aircraft serviceability.*

Designers, therefore, should be given the clearest possible direction on maintenance requirements so that ease of servicing may

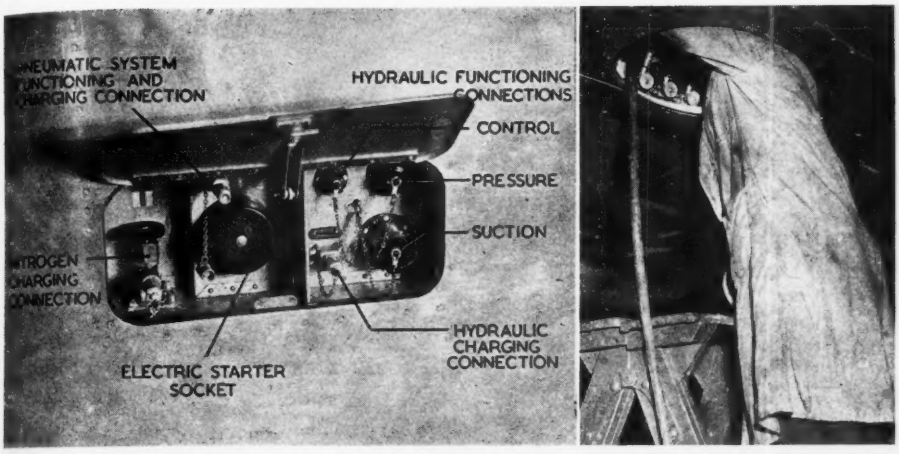


Fig. 39.

Design for easy servicing.
The central servicing point of the Valetta (*left*) R.A.F. transport aircraft on the outside of the fuselage facilitates recharging from ground equipment. The Hastings (*right*) R.A.F. transport aircraft also has a central servicing hatch under the centre fuselage.

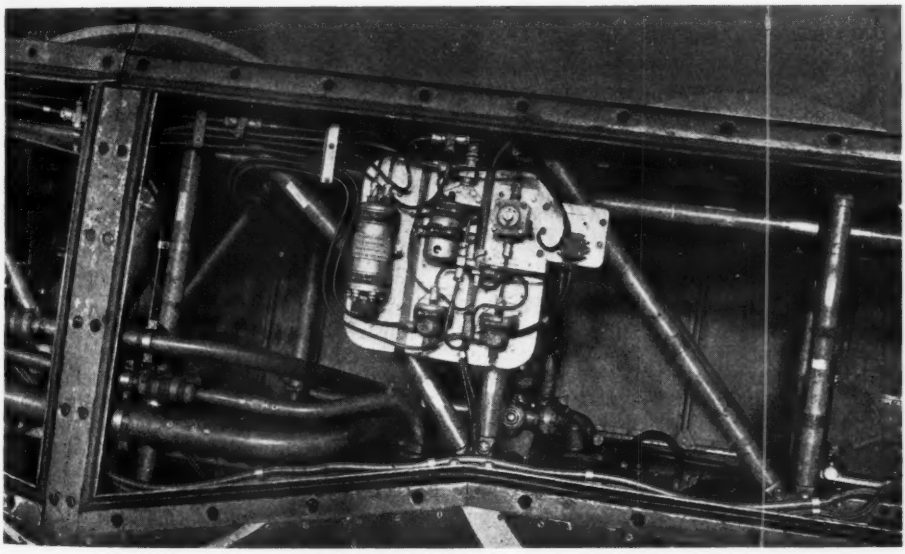


Fig. 40.

Design for easy servicing.
Wherever possible the accessory components of a particular service should be grouped together to facilitate fault finding. In this case, the pneumatic components are grouped together on one panel.

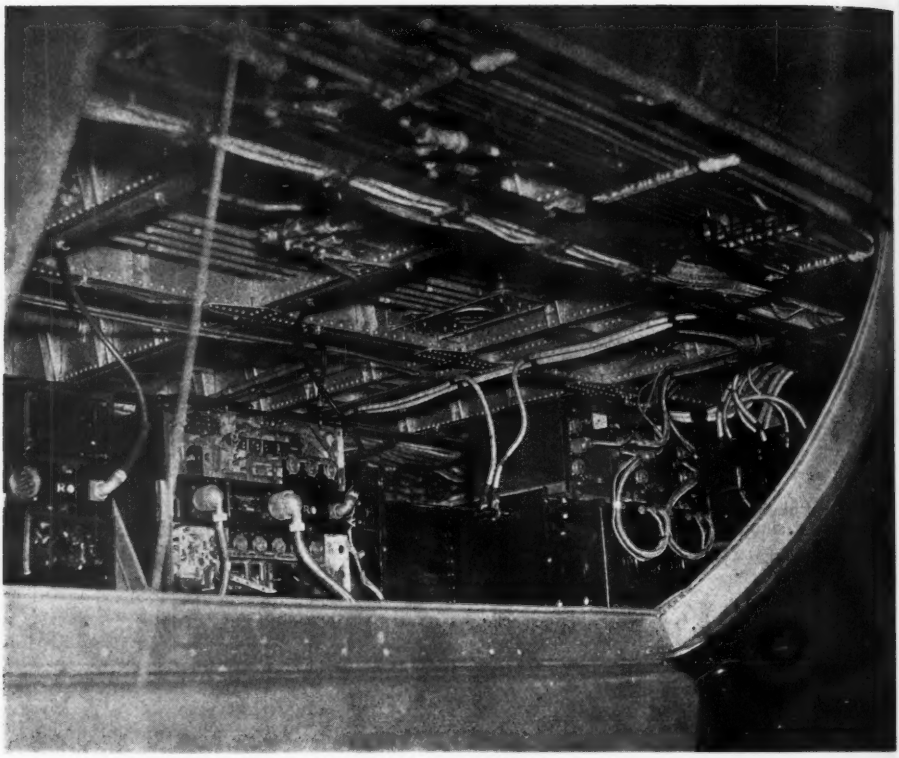


Fig. 41.

Design for easy servicing.

The Valetta R.A.F. transport aircraft has easily accessible radio equipment installed in the under-belly of the front fuselage at arms' height. Multi-plugs and sockets are extensively used for electrical connections. Note the almost diagrammatic layout of pipelines, controls and wiring under the flooring of the cabin, which assists tracing defects.

be regarded as complementary to the operational performance. If you agree that successful aircraft design depends mainly on practical experience then obviously very close collaboration is necessary between operators and manufacturers in order to understand each other's problems and to improve the breed of aircraft in every way. Fig. 44 shows what can be accomplished by joint supervision of a specification by our American friends.

To ensure that aircraft designers are made more aware of the maintenance requirements of the Royal Air Force, the machinery and organisation for the collection and dissemination of design information has been considerably improved, both in the Air Ministry and the Ministry of Supply. The focal point of most of the practical information on servicing requirements is the Air Ministry Servicing Development Unit. A.M.S.D.U., as it is officially known, is responsible for planning servicing schedules for all technical equipment in the Royal Air Force, concurrently with investigation of servicing methods and other allied problems. This important Unit has a vast programme of work, both long term and short term, which should ultimately be of inestimable benefit, not only to the Royal Air Force, but the Aircraft Industry at large.

7. COMPARATIVE COSTS

The key to all the measures for economy is greater flying intensity, which depends on operational and administrative efficiency and aircraft reliability. In order to illustrate the effect of varying rates of flying effort on the total economy, Fig. 45 has been compiled on certain assumptions for an R.A.F. Flying Training Unit. For example, the time in use before a Service trainer aircraft in peace time becomes obsolete has been taken as five years, the flying life as 5,000 flying hours, the initial cost as £10,000 and the cost of daily servicing personnel at £300 per airman per annum. These are arbitrary figures and do not represent the total cost, since there are overheads such as the airfield, administrative personnel, second, third and fourth line servicing personnel in support, spares and equipment, and so on, which have been excluded to emphasise the main variants. On this basis it will be seen that since the number of aircraft required varies inversely with the rate of flying, the 5 year cost in sterling is over 1¾ million pounds for a flying intensity of 10 hours per month per aircraft. This cost is reduced to just over ¼ million pounds if the flying intensity can be maintained between 70 to 80 hours per month.

The economies possible by improving the utilisation shown by the foregoing illustration do not relate to operational aircraft, where the cost is dictated by the number of aircraft required to meet the political, strategic or tactical demand. In such cases economy is achieved when the rate of effort is compatible with keeping the air crews and aircraft exercised for possible opera-

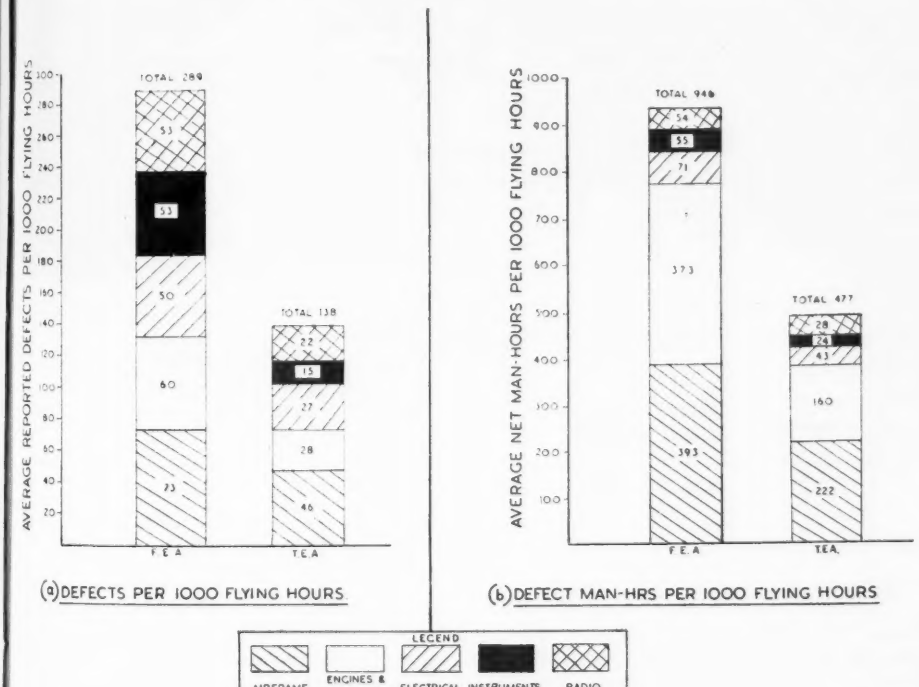


Fig. 42.

Reported defects for three months for typical four-engined and twin-engined aircraft (flying hours: F.E.A. 15,000; T.E.A. 16,000).

Note—This sample concerns 1st and 2nd line servicing only. *Ad hoc* research indicates that actual total defects are about thrice the reported defects, and the actual man-hours per defect almost twice the reported man-hours. Therefore actual total man-hour cost of defects is considerably higher than the reported total.

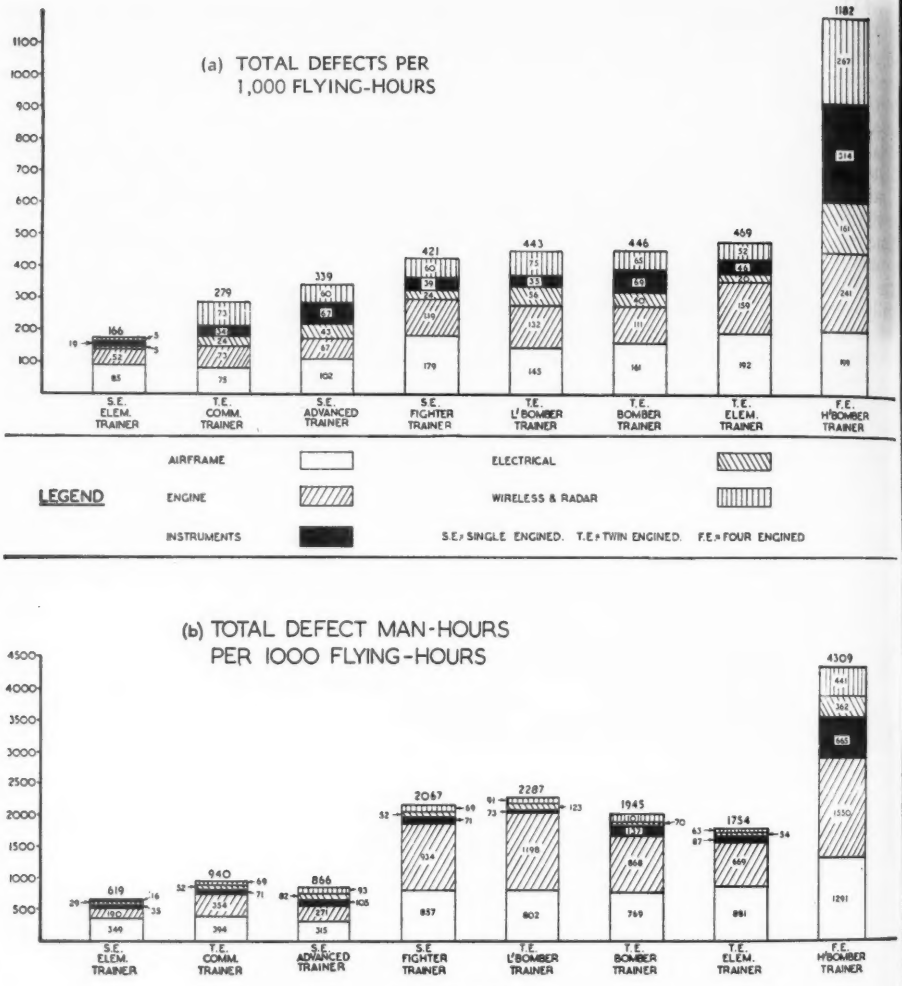


Fig. 43.
Incidence and man-hour cost of defects "in the field" (first-line servicing only).

tions. It should be noted, however, that the cost for higher rates of effort for periods of intensive flying by operational squadrons in war can hereby be assessed.

Lastly, in order to give some idea of the distribution of servicing costs for first, second, third, and fourth line servicing operations, Fig. 46 has been compiled for the same two representative aircraft referred to in regard to defects, the "F.E.A." and the "T.E.A." (The details of the four lines of servicing are given in Appendix C). From this it will be noticed, as for defects, that the costs appear to be proportionate to the size of the aircraft, the costs of the "F.E.A." being about twice those of the "T.E.A." The man-hours have been related to sterling on the assumption that a servicing man-hour rate is four shillings. Whatever conclusions are drawn from this illustration, it is clear

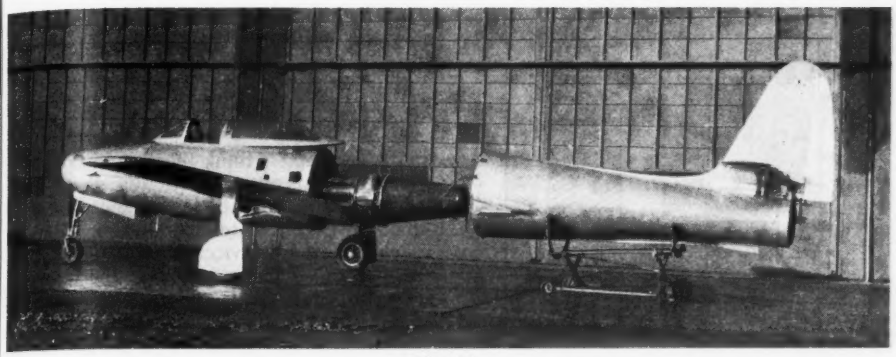
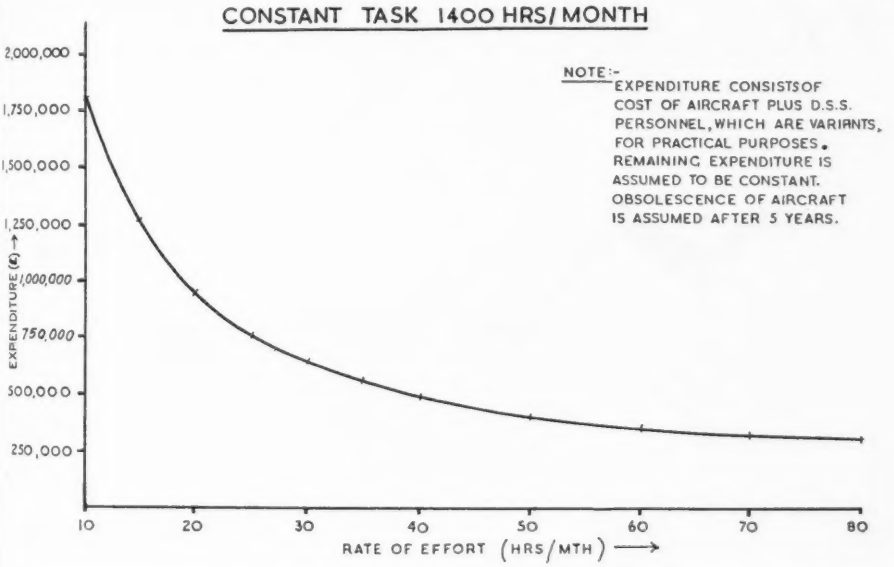


Fig. 44.

Combined design for operational performance, facility of production and ease of servicing. The Republic P.84 Thunderjet. First U.S.A.F. jet fighter in the 600 m.p.h. class with range of over 1,000 miles and ceiling above 40,000 feet, designed and built under joint supervision of the manufacturers and the U.S.A.F. The rear section of the fuselage is quickly removable to permit complete installation or replacement, in 50 minutes, of the axial flow jet turbine power unit.



RATE OF EFFORT (HRS/MTH)	10	15	20	25	30	35	40	50	60	70	80	
a) NO. OF AIRCRAFT REQUIRED TO ACHIEVE TASK	140	93	70	56	46·6	40	35	28	23·3	20	17·5	
b) NO OF D.S.S. PERSONNEL ESTABLISHED	265	188	150	127	112	101	93	82	74	69	65	
c) NO. OF AIRCRAFT AWAITING SPARES	2·8	1·86	1·4	1·12	0·93	0·8	0·7	0·56	0·47	0·4	0·35	
d) COST OF AIRCRAFT REQUIRED TO ACHIEVE TASK	1400,000	930,000	700,000	560,000	466,000	400,000	350,000	280000	233,000	200,000	175,000	£
e) COST OF D.S.S. PERSONNEL ESTABLISHED	398,000	282,000	225,000	191,000	168,000	152,000	140,000	123,000	111,000	103,000	97,000	£
f) COST OF AIRCRAFT AWAITING SPARES	28,000	18,600	14,000	11,200	9,500	8,000	7000	5600	4,700	4,000	3,500	£
g) EXPENDITURE (d+e+f) FOR 5 YEARS.	1826000	1230,600	939,000	762,200	643,300	560,000	497,000	408,600	348,700	307,000	275,500	£

Fig. 45.

Five year expenditure required to support a constant task at varying rates of effort.

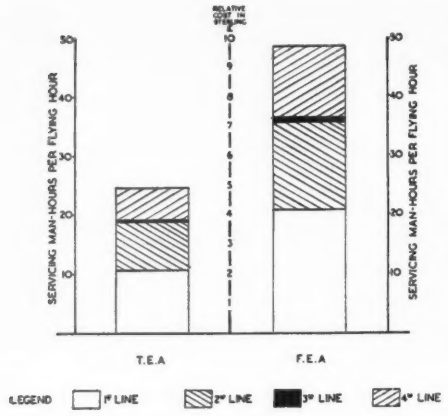


Fig. 46.
Typical servicing costs.

that the distribution of the servicing costs lies too heavily *in the field* (represented by first line servicing).

8. CONCLUSION

To sum up. I think there is no doubt that during the recent years of the development of the aeroplane, the maintenance difficulties and costs have tended to increase, the incidence of unserviceability to prolong the periods of servicing, decrease the utilisation rate to uneconomic levels and make the provision and supply of tradesmen, spares and associated equipment, a problem of the first magnitude in the Royal Air Force.

I have tried to show how the Royal Air Force has met these difficulties and in its search for greater economy how it has improved its planning and administration.

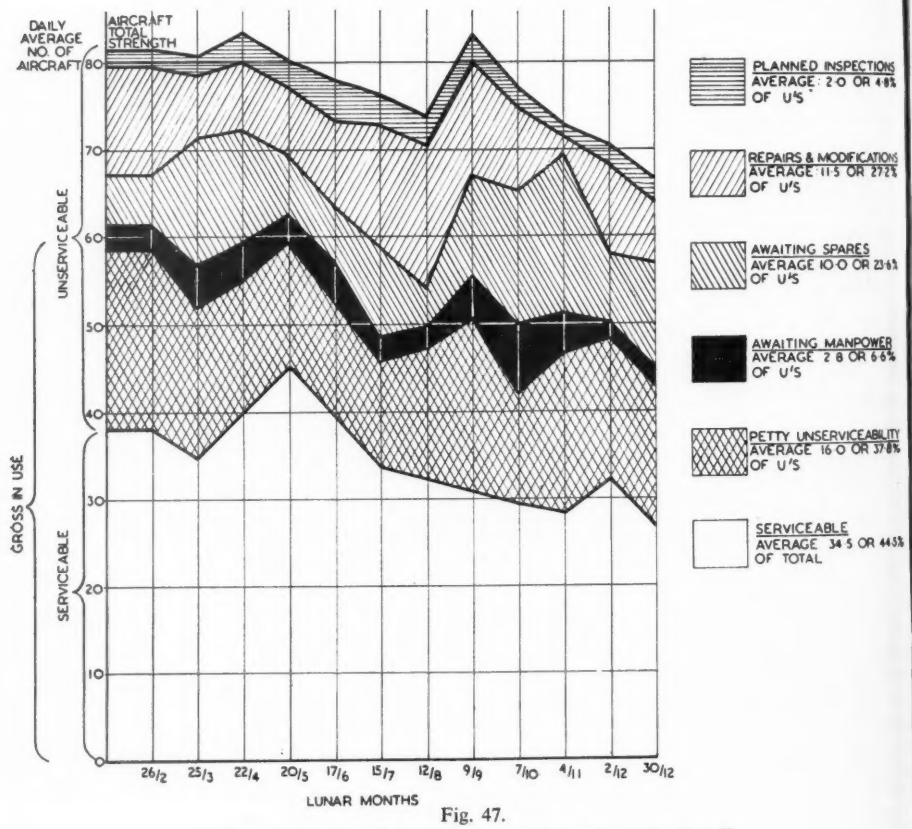


Fig. 47.
Daily average aircraft state for a training unit of the R.A.F.

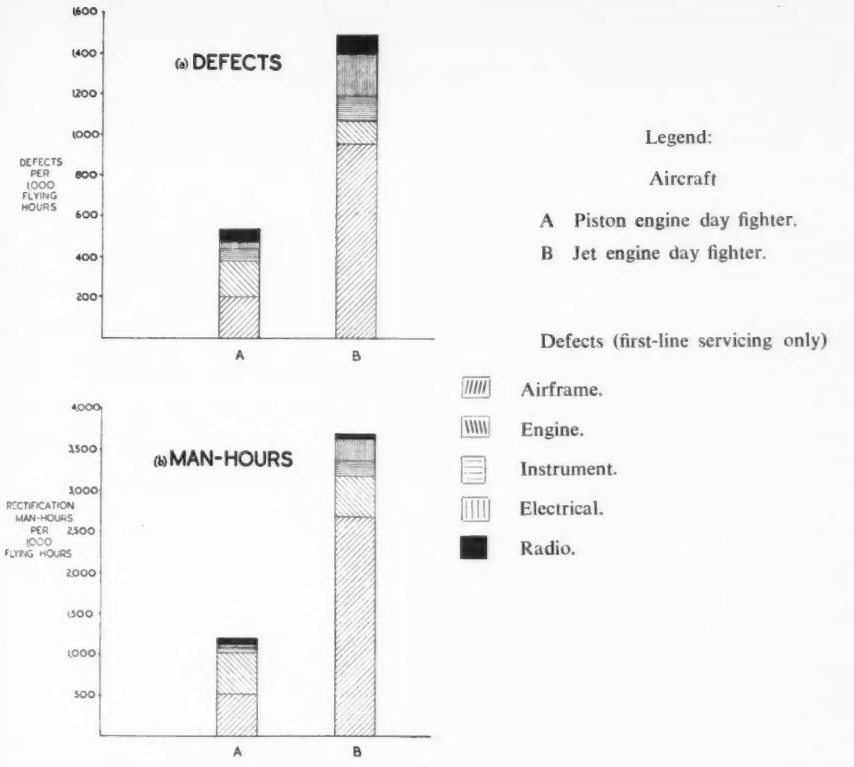


Fig. 48.
Comparison of defect rates for piston and jet engine aircraft (limited sample of 1,000 flying hours).

how it has evolved new techniques and methods of servicing, how it controls and progresses its flying and servicing tasks and tries to measure the results of its efforts by accounting for every flying hour and every man-hour.

Nevertheless, we should not delude ourselves that these quantitative improvements are a substitute for qualitative requirements; that complicated planning and administration for aircraft maintenance can make up for deficiencies in the quality of men and aircraft, or increase that flexibility of operation that an air force should always possess. Although the Royal Air Force always endeavours to provide high quality tradesmen to maintain its aircraft in peace time, it would be wrong to suppose that the same quality of tradesmen would be available in war. *Therefore, it is no good designing aircraft which need supermen to maintain them.*

I hope that designers will think of these things when designing future aircraft for the Royal Air Force. I feel sure that if aircraft designers and the Aircraft Industry as a whole, whether in detail drawing offices or experimental shops, appreciate the maintenance problems of the Royal Air Force, then they will respond as they have always responded. In the past, when the demand was for "operational performance," we got the immortal Hurricane and the Spitfire, the Mosquito, the Lancaster, the Sunderland and many others that gave the Royal Air Force its supremacy in the last war.

Now I suggest there is an urgent demand for "easier maintenance" if we are to win the battle for man-hours.

The interpretation of the problems and the opinions expressed are my own and not necessarily those of the Air Ministry. Also, I should like to pay tribute to the Air Ministry research and scientific officers and other officers of the Royal Air Force, whose ideas and work form the background to this paper.

APPENDIX "A"

THE THEORY OF THE FLYING AND SERVICING CYCLE

INTRODUCTION

1. This theory was produced by the Coastal Command Operational Research Section when they were seeking the solution to the problem of how to obtain more flying from existing resources in 1942. It was the first attempt ever made at a general theory relating the principal factors governing the flying and servicing of aircraft from the administrative angle; and although it was evolved independently of the work already done in Flying Training Command, it used many of the basic assumptions which were implicit in the Flying Training Command task chart of that time. Some of those assumptions, although implied, had not previously been formulated. Some important new ideas were introduced, such as the need for *a pool of aircraft* when flying is irregular and servicing man power is scarce, and *especially the desirability of having aircraft awaiting man power,* which had hitherto been regarded as a sign of inefficiency. Another false test of efficiency had been the ability to maintain 70 per cent. to 80 per cent. serviceability demanded by operational commanders, which this theory shows to be possible only when the flying effort is sufficiently small or deliberately curtailed in anticipation of expected effort of short duration.

2. It is now recognised that this theory is only applicable to the special cases where perfect servicing stagger can be maintained (see Fig. 9). None the less, it applies to many types of unit with reasonable accuracy and is a most useful aid to clear thinking as to cause and effect in the administration of a flying unit, making due allowance for all the variable conditions.

THE THEORY

3. Let q = number of flying hours between terminations of successive major inspections, representing one cycle.

p = average length of each sortie in hours.

Then q/p = number of sorties in each cycle.

4. If it is assumed that an aircraft does not fly more than one sortie per day, and that no petty unserviceability occurs during a day of 24 hours on which it operates,

then F = number of flying days in each cycle

and $F = q/p$.

5. During the cycle there will be a number of days S on which the aircraft is being serviced. In general these will be inversely proportional to the number of men employed, but a lower limit is set by the employment of a maximum economic team, and this value will be used, therefore

S = number of days that the aircraft is undergoing periodic servicing.

6. Let M = number of days that the aircraft is awaiting spares, and

D = number of days that the aircraft could be flying and is not.

Also let f = proportion of days flying,

m = proportion of days awaiting spares,

s = proportion of days being serviced, and

d = proportion of days serviceable but not flying.

Then
$$f = \frac{F}{F+M+S+D}$$
$$m = \frac{M}{F+M+S+D}$$
$$s = \frac{S}{F+M+S+D}$$
$$d = \frac{D}{F+M+S+D}$$

7. If periodic inspections are staggered and assuming repairs and the need for spares to occur at random, the distribution of the condition of all aircraft in a squadron on any one day will correspond to the distribution of the condition of any one aircraft within a cycle. So that if there are n aircraft in the squadron then

fn = number flying,

sn = number being serviced,

mn = number awaiting spares,

dn = number which could be flying but are not.

SERVICEABILITY

8. The serviceability y may be defined as the proportion either flying or ready to fly

$$i.e. \quad y = \frac{F+D}{F+M+S+D} \quad . \quad . \quad . \quad (1)$$

9. The effort will be a maximum when aircraft fly whenever they are serviceable, (D is eliminated) so that the serviceability for maximum effort is given by the equation

$$x = \frac{F}{F+M+S} \quad . \quad . \quad . \quad . \quad (2)$$

10. In a typical case (see Fig. 2) x is approximately 33 per cent. Thus the former conventional R.A.F. serviceability standard of 75 per cent. is not the serviceability for maximum flying effort, and is only obtainable by having a number of "dead" days, D, which are readily calculable from equation (1). In the above-quoted case where $x=33$ per cent., $y=75$ per cent. when $D=5F$, *i.e.* when aircraft fly for only one sixth of their serviceable time. This does not mean that six times as much flying is available, for if the D dead days are eliminated they would become

$D.\ \frac{F}{F+M+S}$ flying days

$D.\ \frac{M}{F+M+S}$ days awaiting spares, etc.

$D.\ \frac{S}{F+M+S}$ days undergoing servicing

FLYING INTENSITY

11. Let I = daily flying intensity
= average hours flown by each aircraft on each of $(F+M+S+D)$ days
$= fp$

$$= \frac{Fp}{F+M+S+D} \quad . \quad . \quad (3)$$

Eliminate F plus D from equations (1) and (3)

$$I = \frac{q}{M+S}(1-y) \quad . \quad . \quad (4)$$

N.B.—In the extreme case, $I=0$ when $y=1$, *i.e.* serviceability is 100 per cent. when there is no flying, as is obvious. The maximum value of I is given by equation (3) when $D=0$.

$$I_{max} = \frac{pq}{p(M+S)+q} \quad . \quad . \quad (5)$$

It will be seen that the maximum flying intensity can be increased by increasing p or q, that is, flying serviceable aircraft longer or lengthening the major servicing cycle, or by reducing S or M, that is, reducing turn-round time for servicing or improving spares supply.

12. In the typical case referred to above:

$q = 480$ hours
$p = 10$ hours
$F = 48$ days $\left(= \frac{480}{10}\right)$
$S = 81$ days
$M = 15$ days

$$\text{Then } I_{max} = \frac{10 \times 480}{10(81+15)+480}$$
$$= 3.33 \text{ hrs./a.c/day}$$
$$= 93.25 \text{ hrs./a.c/28 day month}$$

If serviceability is to be maintained at 75 per cent., then from equation (4)

$$I = 1.25 \text{ hrs./a.c./day}$$
$$= 35 \text{ hrs./a.c/28 day month}$$

13. In other words, in the case considered, 75 per cent. serviceability is only obtainable by reducing the potential flying output by more than one half, and there is an intensity of effort corresponding to any other given value of serviceability.

MAN-POWER REQUIREMENTS

14. There are S days in the cycle when each aircraft is being serviced, making a proportion s of the total days. Therefore if there are n aircraft, perfectly staggered, the number of aircraft being serviced will be sn, and if $D=0$:—

Number of aircraft being serviced $= sn$

$$= \frac{Sn}{F+M+S}$$

15. This will require a number of men 'N', sufficient to provide a maximum economical team for each unserviceable aircraft.

16. If D is not zero, the number of aircraft being serviced will be

$$\frac{Sn}{F+M+S+D}$$

and this will require a smaller number of men, say "N".

$$\text{Then } \frac{\text{"}N\text{"}}{\text{'}N\text{'}} = \frac{\frac{Sn}{F+M+S+D}}{\frac{Sn}{F+M+S}} = \frac{F+M+S}{F+M+S+D}$$
$$= \frac{1-y}{1-x}$$

(from equation (1) and (2)) . . (6)

17. That is to say, the number of men required is proportional to the unserviceability, as would be expected.

APPLICATION OF THE THEORY

18. The case when $D=0$ is never met with in practice. It would involve an aircraft flying straight out of the hangar as soon as it is serviceable, and returning there and being worked on as soon as it is unserviceable. Even if there is constant operational opportunity, in order to achieve reasonable regularity of effort some aircraft will always be held in reserve to take the place of those which might go unserviceable just before being despatched on a sortie. In most parts of the world bad weather prevents flying from time to time, and there will always be variations in the arisings of repairs and the need for spares.

19. Therefore, the maximum effort corresponding to serviceability x is never achieved, but we can decide on a value of y for a particular unit, and thereby calculate the anticipated flying effort and average aircraft state in the form:—

Effort = 28 *In* flying hours per month

Aircraft flying = fn

Aircraft serviceable and not flying = dn

Aircraft u/s for spares = mn

Aircraft being worked on = sn

20. So far no consideration has been given to aircraft which may be unserviceable and awaiting attention because servicing personnel are already fully employed. If there are enough men to work on sn aircraft only, aircraft will appear in this category of awaiting man-power whenever more than sn aircraft are unserviceable.

21. When there are aircraft awaiting man-power, the theory as so far discussed is unaffected, except as regards serviceability.

For if D_F = days when aircraft are serviceable and not flying

and D_S = days when aircraft are u/s awaiting man-power.

Then if we substitute (D_F+D_S) for D the general theory is unchanged except that the true serviceability is given by:—

$$y=\frac{F+D_F}{F+M+S+D_F+D_S}$$

which is less than $y=\dfrac{F+D_F+D_S}{F+M+S+D_F+D_S}$

That is to say the effect of this correction is to give a lower serviceability figure whenever there are aircraft unserviceable awaiting man-power and the higher value y is actually the upper limit of serviceability for a given set of conditions.

22. If there are never less than fn aircraft available for flying the unit will be able to complete its flying task and, assuming m to be constant, if there are never more than $(fn+dn)$ aircraft serviceable there will always be enough aircraft (sn) to be worked on to prevent partial employment of servicing personnel.

23. This introduces the idea of a range of serviceability, with limits set by the minimum availability of serviceable and unserviceable aircraft necessary for completion of the flying task and the resultant servicing task. (See item 37 in Appendix B.)

THE POOL

24. It becomes apparent that in any unit, due to inevitable variations, there will always be a number of aircraft, dn, which are either serviceable and awaiting flying or unserviceable and awaiting man-power. They are referred to as the "pool" aircraft.

25. The serviceable element of the pool should be present always for the reasons given in para. 18. If it is drawn on as a source of useable aircraft for any length of time, as during a spell of fine weather at a training unit or to make the most of a particular operational opportunity, it will tend to become unserviceable, and so there will be either:—

(*i*) an increase in the number of aircraft being worked on, or, if men are not freely available

(*ii*) the appearance of the unserviceable element of the pool, awaiting man-power.

26. For economical use of man-power the second method is preferable, as it will permit continued use of men in maximum economical teams on the planned number of aircraft "on the floor." A further most important function of aircraft unserviceable and awaiting man-power is to provide a reserve of work during bad weather and other periods of reduced flying activity, so building up reserve serviceability for the next good weather period.

27. Therefore the dn aircraft which are undesirable from the point of view of maximum flying effort under ideal conditions, are, in fact, essential to the performance of any regular (not necessarily routine) flying

plan and to the economical use of manpower. They form a pool which varies between serviceability and unserviceability in response to variations in the rate of flying and are relatively more numerous as this variability increases.

CALCULATION OF POOL FOR ROUTINE FLYING ROLE

28. The function of the "pool" is to smooth out the fluctuations in the flying cycle caused by weather, and other factors. Its size will therefore vary with the degree of fluctuation. The weather factor gives the number of days (or nights) in the month fit for flying, *e.g.* 21 out of 28, but this alone does not give the distribution throughout the month of good and bad days. The worst conditions, taking the foregoing figures, would be consecutive periods of 21 and 7 days good and bad weather respectively. The best conditions might be three good days followed by one bad day throughout the month or perhaps $1\frac{1}{2}$ good days and $\frac{1}{2}$ bad.

29. The pool should contain sufficient aircraft (*i*) for periods of bad weather to keep up the in-put of u/s aircraft for constant employment and (*ii*) for periods of good weather to supplement the output of serviceable aircraft from servicing to meet flying requirements. If servicing is constant on every day of the month, while flying occurs on only a proportion of the days, on any flying day the rate of decline of serviceability is greater than the recovery rate which is constant, while on a non-flying day the rate of decline is nil.

30. In addition to the weather factor w, the average cycle of weather variation is required to give the maximum variation of good and bad weather respectively for which the pool is to provide. If the cycle of weather variation (to be obtained by frequency distribution analysis of Met. records) say, is 8 days, and w is .75, then it may be expected that the weather will present a succession of six good day and two bad day periods.

Therefore if w = weather factor

d = weather cycle

n = daily output of serviceable aircraft from servicing men (constant)

then arising of unserviceable aircraft per flying day $= n \times \frac{1}{w}$

excess of arisings over output $= \left(n \times \frac{1}{w}\right) - n$

$= n\left(\frac{1}{w}\right) - 1$

Number of consecutive flying days $= w.d.$

Therefore total excess of arisings for flying period $= w.d.n.\ \left(\frac{1}{w}\right) - 1$

$= d.n.\ (1 - w) \quad (i)$

Number of consecutive non-flying days $= (1 - w)\, d$

Therefore total output for non-flying period $= (1 - w)\, d.n.$

or $\quad d.n.\ (1 - w) \quad (ii)$

(*i*) and (*ii*) are the same, so that a pool of this size will satisfy both requirements.

31. If a period of good weather exceeds $w.d.$ days in length, the daily flying programme will be progressively curtailed by lack of serviceable aircraft. If a period of bad weather exceeds $(1 - w)\, d.$ days, servicing personnel will be only partially employed through lack of work. In the latter case if the monthly flying task is achieved by increase of daily intensity there will be a remainder of servicing work at the end of the month, unless an extra effort (*e.g.* overtime) is successful in clearing it. (See items 12, 14 and 34 in Appendix B.)

CALCULATION OF POOL FOR VARIABLE OR FLEETING OPPORTUNITY FLYING ROLE

32. When the number of aircraft in use is not constant but varies up to the maximum available on those occasions when operational requirements arise, the pool varies from nil to total aircraft, less the sum of those under attention and on routine flying. It is simply a remainder. The number of aircraft flying and the size and state of the pool are estimated according to present and expected future requirements, but the number of aircraft which may be flown constantly, without affecting the pool, must be known for the guidance of the technical officer in charge of servicing. While this number is being flown there is no change in the size or state of the pool, servicing input equals servicing output and the unit is in equilibrium (see Figs. 3 and 4).

APPENDIX "B"

TYPICAL TASK CHART FOR R.A.F. UNIT

FLYING AND SERVICING TASK CHART FOR NON-OPERATIONAL UNITS

Command: Transport. Group: 4. Unit: 11 H.T.C.U. Task Chart Ser. No. 7. Date: 1/12/46.

Complementary to Establishment No. 678. Date: 1/12/46.

	AVERAGE FACTORS		
	TRAINING COMMITMENTS		
	Aircraft Type & Mark	YORKSHIRE Mk. I.	
	Aircraft Function	Training	
1	Intake strength (Pupils or Crews)	20	
2	Weekly intervals between intakes	2	
3	Number of Courses concurrently	5	
4	Gross pupil or crew population	100	
5	Net pupil or crew population	90	
6	Length of Course (weeks)	10	
7	+ Incidental (or other wastage allowance)	11%	
8	Number of pupils per crew	7	
9	Hours per pupil or crew (day and/or night)	70	
	FLYING PLAN Airfield	Bisley	
	Day or Night flying	Day	
10	Aircraft hours per 28 days (day/night)	2800	
11	Minimum weather fitness No.	6	
12	Weather factor	.75	
13	Days/Nights planned for flying per 28 days	16.5	
14	Weather cycle	3	
15	Tarmac time per day/night	9.5	
16	Target hours per flying day/night	170	
17	Net in-use aircraft	26	
18	Backers-up A/C.	5	
19	Total gross in-use aircraft (day/night)	31	
	SERVICING PLAN		
	(*a*) Monthly Arisings		
20	Inspection cycles	50/100	
21	Monthly arisings of minor inspection	28	
* 22	Monthly arisings of base inspection	28	
23	Monthly arisings of A/C. on unit repairs	51.4	
24	Total monthly arisings of aircraft	107.4	Average
25	Average daily A/C. output for 28 days	4.9	22
26	Turn-round time minor inspection	1.0	working
27	Turn-round time base inspection	2.0	days
28	Turn-round times for repairs/modifications	1.5	per 28 days
	(*b*) Aircraft U/s. daily		
29	U/s. daily on minor inspection.	1.3	
* 30	U/s. daily on base inspection	2.6	
31	U/s. daily on repairs/modifications	3.5	
32	U/s. daily awaiting spares (A.O.G.)	0.6	
33	Total aircraft U/s. daily	8.0	
	POOL		
34	A/C. serviceable (awaiting flying) plus A/C. unserviceable (awaiting manpower)	Total 4	
35	**AIRCRAFT ESTABLISHMENT**	43	
36	**SERVICING PERSONNEL ESTABLISHMENT**	343	
	COMPARATIVE FACTORS		
37	Serviceability range % (flexibility factor)	72-82	
38	Hrs. per flying day/night per net in-use A/C.	6.5	
39	Hrs. per flying day/night per gross in-use	5.5	
40	Hrs. per month per established A/C.	65	
41	Flying hours per servicing man	8.2	
42	Servicing men per established A/C.	8.0	

REMARKS: Manning strength of servicing personnel must not fall below 90 per cent. of total establishment, or 80 per cent. in any particular trade.

*Progressive inspection system, *i.e.*, major inspection divided between eight base inspections.

APPENDIX "C"

DETAILS OF SERVICING OPERATIONS IN THE ROYAL AIR FORCE

1. FIRST LINE SERVICING in the R.A.F. is conducted by semi-skilled tradesmen, diluted with unskilled labour, but supervised by skilled N.C.O. tradesmen. The work undertaken by first line servicing personnel may be categorised thus:—

(*a*) *Daily, before and after flight routine and calendar inspections*: consisting of replenishment operation, superficial examination of structure, engines, and services, mainly of a functional nature, and cleaning.

(*b*) *Rectification of minor defects*: discovered by tradesmen on routine servicing, or reported by flight crew. Rectification is mainly by replacement of minor parts, or by minor repairs, and is within the capacity of semi-skilled labour.

2. SECOND LINE SERVICING is conducted by skilled tradesmen diluted by semi-skilled, and to a slight degree by unskilled labour. Supervision is carried out by skilled N.C.O. tradesmen. The work undertaken may be categorised thus:—

(*a*) *Periodic routine inspection*: done at prescribed flying hour periods, and consisting of detailed examination of structure, engines, and services, for deterioration, functional tests of services, lubricating and cleaning;

(*b*) *Rectification repair and modifications*: the repairs and rectifications are those beyond the capacity of the first line servicing; as a rough guide they take longer than a day but do not exceed five days. The modifications are categorised and as a general guide only those which take less than 30 man hours are done by second line units;

(*c*) *Component servicing*: components are "lifed" to phase in with routine servicing. Scheduled servicing of the component is carried out in "bays" when the components are removed from the aircraft. If the overhaul or reconditioning life is reached the component is passed on to fourth line servicing.

3. THIRD LINE SERVICING is conducted in the main by skilled tradesmen, diluted to a small extent by semi-skilled and unskilled labour. The work undertaken may be categorised thus:—

(*a*) *Repair*: repair arisings beyond the capacity of the user units, but repairable on site at the user unit.

(*b*) *Salvage*: salvage of aircraft:—

(*i*) Beyond the capacity of the unit to repair and, because of geographical location, or to absence of jigs and special equipment, not repairable at the unit.

(*ii*) "Written off," but having serviceable or repairable equipment for re-issue for service use.

(*iii*) "Written off," and not having any serviceable or economically repairable equipment, or physically impossible to be salvaged; such materials that may remain being reduced to produce.

4. FOURTH LINE SERVICING is conducted almost entirely by skilled tradesmen, and may best be defined as "overhaul" of equipments. The work undertaken is categorised thus:—

(*a*) *Category B. Repair*: which includes repair to aircraft and equipment damaged by accident, airframe overhaul, and installation of major modification.

(*b*) *Engine overhaul*: complete overhaul of aero-engines to "as new" standards.

(*c*) *Component overhaul*: overhaul of aircraft associated components and assemblies.

(*d*) *General engineering*: general engineering practices allied to aircraft servicing repair and overhaul.

APPENDIX "D"

DETAILS OF EXAMPLES OF INFERIOR DESIGN FOR EASE OF SERVICING RELATING TO CURRENT AIRCRAFT TYPES IN THE R.A.F.

Serial No.	*Design Defect*	*Type of Aircraft*	*Remarks*
PART 1.—AIRFRAMES			
INACCESSIBILITY			
1.	(*a*) It is impossible to remove the pneumatic bottle for draining without first removing the fuselage fuel tank and the hydraulic accumulator.	Fighter	This could have been avoided by fitting the component in an alternative position or by incorporating a drain plug.
	(*b*) It is impossible to either remove or drain the pneumatic filter without removing the rear fuel tank.	Fighter	This point does not seem to have been considered when the rear fuel tank was installed as a variant from the other Marks of the type.
	(*c*) It is impossible to remove the rear fuselage fuel tank pulsometer pump without removing the fuel tank.	Fighter	A suitably positioned inspection panel would have avoided this fault.
	(*d*) It is impossible to remove the accumulators or inspect the rear fuselage without first removing the ballast weights.	Fighter	Alternative positioning of ballast weight stowage should have been considered.
	(*e*) It is necessary to remove the blind flying panel before the flap control valve can be removed.	Fighter	Flap control valves could have been positioned in more accessible position.
	(*f*) It is necessary to remove the radiator fairing before the coolant radiator can be inspected properly. The fairing is secured by numerous small screws and takes at least 5 man hours to remove.	Fighter	A strengthening attachment strip and fewer larger screws would have simplified matters from the servicing aspect.
	(*g*) It is impossible to utilise the front gun harmonisation plumb bob attachment point without first removing the ventral tank.	Fighter	Suggest this was a case of lack of foresight.
	(*h*) It is necessary to remove the hydraulic header tank before the vacuum oil separators can be changed.	Fighter	Relative location of components could have been improved.
	(*j*) In order to change the chromate crystals in the rear inboard fuel tank it is necessary to partially remove the fuel tank.	Flying Boat	Position of inspection panel was not helpful.
	(*k*) Windscreen de-icing tank filler cap is extremely inaccessible which complicates filling procedure.	H. Bomber	Position of tank could have been better.
	(*n*) Panels giving access to the mainplane bolts, engine ribs and fuel tanks from the undercarriage bays are secured by numerous screws and require some time to remove.	H. Bomber	The panels are unstressed and are fitted as dust excluders, suggest they could equally well be secured by quick release fasteners.
2.	The lubrication of the following points is impossible with standard lubrication guns due to the positioning of the nipples:—		Lubrication trials with the mock-up or prototype would have revealed these faults.
	(*a*) Aileron centre hinge bearings.	Fighter	
	(*b*) Aileron connecting lever coupling pin.	Fighter	
	(*c*) Nose wheel shock absorber top pivot bearing.	Fighter	
	(*d*) Windscreen wiper gear box.	Fighter	
3.	Flaps, tail wheel and bomb door hydraulic flow control valves are so positioned that they must be removed before the valves can be changed. This is frequently necessary.	L. Bomber	By reversing the control valves these valves could be changed *in situ*.

Serial No.	*Design Defect*	*Type of Aircraft*	*Remarks*
4.	Cover over flap jack is secured by screws. This makes removal a longer process than is necessary.	H. Bomber	Suggest quick release fasteners should be used wherever possible.
5.	Ventral drop fuel tank is located by two dowels which are square in cross section, this makes it difficult to locate the tank when fitting.	Fighter	Suggest the dowel pins be tapered to assist fitment of the tank. (Conic sections could be used more frequently for locating purposes.)
	INDIFFERENT INSTALLATION		
1.	Electrical accumulators are so installed that if the accumulators "boil" due to overcharging there is a strong probability of the acid dripping on to the flying control rods.	Trainer	Careful positioning of accumulators and fitting of an effective tray to catch any acid which may spill are essential.
2.	The plug for the external electrical supply is in such a position that a starter battery cannot be connected from the ground without a ladder.	H. Bomber	It is essential that starter plugs be located in an easily accessible position.
3.	The hydraulic system accumulator is not fitted with an air pressure gauge and the charging point is inaccessible when the ventral fuel tank and ammunition containers are fitted.	Fighter	Checking air pressure and recharging is unnecessarily difficult. Suggest this should be considered during design.
4.	The hydraulic system air bottle, which becomes partially filled with hydraulic fluid has no provision for draining.	Fighter	The bottle has to be removed for draining: the incorporation of a drain plug would have made this unnecessary.
	LACK OF STANDARDISATION		
1.	Lockheed main undercarriage legs fitted and Turner tail wheel strut. These require different fluids and the inflation procedure varies.	Trainer	Considered to be an unnecessary lack of standardisation.
2.	The use of a different type of jacking pad for every type of aircraft in service. This is a serious difficulty when an aircraft requires a wheel change on an airfield not equipped with that type of aircraft jacking pad.	GENERAL	Suggest that except in very special cases this should be avoided by instructions to manufacturers on the type of jacking pad they should fit.
3.	Pipelines are now identified by various combinations of coloured bands. Hence the tradesmen must try to memorise the coding or refer to a publication.	GENERAL	Would it not be equally easy from the manufacturer's point of view to use bands on the pipelines with the name of the system printed on the band?
	CAUSING UNNECESSARY WORK		
1.	Hydraulic filters are often positioned as to result in considerable loss of fluid when filters are removed for cleaning.	GENERAL	Suggest filter element be removed from top of filter and that filter be installed level with or above reservoir fluid level. Alternatively an isolation valve be introduced.
2.	Pilot's seat takes 40 man-minutes to remove, this is a necessary preliminary to the adequate inspection of the cockpit.	Fighter	The fitting of nuts locked by spring washers instead of split pins to the seat raising and lowering quadrant greatly reduces the time required.
	PART 2.—ENGINES		
1.	Oil draining facilities very poor.	GENERAL	Suggest fitment of waste pipes which would carry oil to a convenient draining position in the nacelle.
2.	Often no provision is made for cleaning and flushing out oil system.	GENERAL	Flushing of oil systems is necessary especially after a bearing failure. Could the oil system be arranged so that any flushing rig can be quickly connected and the oil system efficiently cleaned?
3.	Auxiliary gear boxes and accessories are inaccessible on many types.	GENERAL	This makes checking of oil level and changing of accessories difficult. *Will designers carefully consider this.*

Serial No.	*Design Defect*	*Type of Aircraft*	*Remarks*
4.	High tension sparking plug leads difficult to change.	GENERAL	Suggest this be overcome by manufacturing leads in two sections, the sparking plug end of lead could be connected to the remainder of the lead in the main conduit by means of plug and socket.
5.	Inaccessibility of oil coolers.	GENERAL	Could this be overcome by incorporating hinged panels and simplified methods of securing coolers and pipelines?
6.	Difficult to gain access to fire extinguisher containers.	GENERAL	These containers must be removed for inspection at frequent intervals, therefore easy access is important.
7.	Oil charging of carburettor linkage chamber, necessitating removal of linkage chamber cover. This is a long and difficult job requiring the dismantling of part of the induction system.	One type of engine	Suggest fitment of oil charging nipple to linkage chamber.
8.	Oil tanks common to two engines, complicating draining and flushing in the event of sleeve or bearing failures.	H. Bomber	A separate oil tank for each engine should always be fitted.
9.	Difficulty experienced in removing jet pipe and shroud for Turbine Blades Inspection owing to corroded split pins.	Fighter	Could be obviated by non-corrosive locking devices.
10.	Removal of scavenge oil filters is an unnecessarily difficult task and usually results in oil being spilt.	Fighter	A drain plug would assist in preventing mess and quick release would reduce time.
11.	Assembly of combustion chambers is a long and tedious job.	Fighter	Suggest simpler methods of attachment of combustion chambers and fitting of burners should be designed as these must be removed at frequent intervals at present.

PART 3.—INSTRUMENTS

1. PILOT'S PANEL

The present method of securing instruments by means of nuts and bolts makes difficult the removal of the instruments for servicing. Two men are required, one in front and one at rear of panels to remove securing bolts of instruments. In some aircraft the instruments must be removed and replaced in a definite sequence, owing to small amount of space available behind the panel.

GENERAL

Suggestions:

(*a*) Fit all instruments into their mountings from the front of the panel with fixed anchor nuts fitted to the back of the instrument panel.

(*b*) Have small panels on anti-vibration mountings containing no more than four instruments, with either hinges, or suspended on anti-vibrational mountings similar to the Blind Flying Panel. All the leads to instruments mounted in this way should be sufficiently long and flexible to permit lowering of the panels without undue tension being placed on the leads. No rigid aircraft controls and pipelines should be fitted to such panels.

2. OXYGEN CYLINDERS—CHECKING FOR DATE OF LAST TEST AND CORROSION

It is necessary, owing to the mounting position of the oxygen cylinders, to disconnect the supply lines and remove the cylinders in order that the date stamp on the neck can be seen. It takes five hours to check an installation on one type. It is impossible to make a thorough check *in situ*, and as this inspection is done every 200 hours, the present installation is most unsatisfactory. The same procedure is necessary when checking the oxygen cylinders for corrosion between the coils, as no satisfactory inspection of the cylinders can be made *in situ*.

H. Bomber

To overcome the difficulty of checking the oxygen cylinders for the date of the last test, it is recommended that the date be painted on the cylinders in an easily viewed position. To facilitate ease of checking for corrosion between coils of the oxygen cylinders it is suggested that they be mounted one above the other against the side of the fuselage in two banks.

Serial No.	*Design Defect*	*Type of Aircraft*	*Remarks*
3.	DRAINING OF OXYGEN REGULATOR Owing to the fact that the drain plug is obscured by pipes and electrical leads, it is necessary with the present installation to remove the oxygen regulator in order that access may be obtained to the drain plug. In present circumstances it takes one hour to drain the oxygen regulator.	H. Bomber	In order that the draining of the oxygen regulator can be carried out *in situ*, it is recommended that the position of the mounting for the oxygen regulator be raised six inches, thus reducing the time necessary to carry out this operation.
4.	FIRST PILOT'S D.R. COMPASS REPEATER The electrical leads to this instrument allow no freedom of movement when fitting the instrument. It is first mounted on its panel with distance pieces by the manufacturers prior to the fitting of the panel to the aircraft. Removal and installation of this instrument is thus very difficult and the time to change this instrument is one hour.	H. Bomber	It is recommended that the D.R.C. repeater should be repositioned and the electrical leads be made longer, thus the removal and replacement of this instrument would be made easier.
5.	ELECTRICAL CONNECTORS TO INSTRUMENTS (*a*) The terminal connectors at the back of the electrical instruments are unsatisfactory as none of them are marked. In one case there are over 100 leads to identify (7 to each fuel contents gauge) and it is necessary to mark each individual lead in order that correct connection on replacement of instruments can be carried out successfully. (*b*) The Air Position Indicator is removed on all inspections other than the Terminal. The number of electrical leads to be disconnected is 14.	GENERAL	(*a*) Could terminal connectors be replaced by plugs and sockets with retaining nuts on the plugs of the conventional hexagon type or of suitable shape for use with a "C" type spanner, and not of the type involving a strap spanner? (*b*) Suggest the use of a 14 pin plug in the case of the A.P.I.
6.	OXYGEN ECONOMISERS (*a*) Disconnection of the oxygen economiser at present means removing the economiser complete owing to awkward installation and difficult fitting of the pipeline. (*b*) The economiser has to be removed for strip examinatoin on every Minor Inspection. This is difficult owing to the position of the economiser and requires two men.	H. Bomber Fighter	(*a*) It is recommended that the pipeline to the oxygen economiser be designed to incorporate a loop or length of flexible pipeline. (*b*) The fitting of anchor nuts would eliminate the need for two men. The removal of the economiser would be made easier if the inlet connection was repositioned 90°.
7.	FILTER ON TURN AND BANK INDICATOR This filter has to be cleaned on every 100 hour inspection, and in its present form, the cleaning of the filter takes an unnecessarily long time.	ALL AIRCRAFT	It is recommended that a modification of the filter be made to bring it in line with the filters of the Artificial Horizon and Direction Indicator which are held by a circlip, instead of being held by screws.
8.	LOCKING OF INSTRUMENT COMPONENTS The use of wire as a means of locking instrument components into position is very unsatisfactory. In some cases it is difficult to use locking wire owing to the position of the components, furthermore, great care has to be taken to see that undue strain is not placed on the locking wire.	ALL AIRCRAFT	A very much simpler form of locking is the locking plate, and this is recommended for use wherever possible.
9.	FLEXIBLE DRIVES The use of flexible drives for connecting engine speed generators to aircraft engines is unsatisfactory. Removal of flexible drives is often difficult owing to their position on the aircraft engine.	GENERAL	It is recommended the engine Speed Generators be connected direct to the engine and flexible drives be abolished.

Serial No.	*Design Defect*	*Type of Aircraft*	*Remarks*
10.	LOOSE OLIVES AND NIPPLES		
	The use of loose olives and nipples in instrument pipeline systems makes servicing more difficult as great care must be taken to ensure no loss of olives and nipples.	GENERAL	For ease of servicing it is recommended that fixed olives and nipples be used in every case.
11.	NON-RETURN VALVES		
	In order to get at the non-return valve in the suction system it is necessary to remove the pilot's seat, and as this is the only component for which this is necessary, unnecessary work for the riggers is entailed.	Fighter	If the non-return valve had been mounted on the power plant in the vicinity of of the suction relief valve removal of the pilot's seat would be unnecessary.
12.	BLIND FLYING PANEL		
	The rubber pipes connected to the Blind Flying Panel kink easily due to the bad layout of the main A.S.I. pipeline system.	Fighter	The Blind Flying Panel should be connected to the system in such a way that kinking of pipes is impossible.
PART 4.—ELECTRICAL			
	ACCESSIBILITY OF EQUIPMENT		
1.	Electrical equipment such as motors, rotary convertors, relays, solenoids, cut-outs, voltage regulators, etc., necessitate frequent removal from aircraft for servicing, ease of removal is therefore essential. Mounting bolts are usually accessible at the equipment but nuts are very inaccessible the other side of the mounting plate, bulkhead or bracket.	GENERAL	Recommended that anchor type nuts should be fitted wherever any difficulty is likely to occur in removing or replacing equipment.
2.	In some cases equipment cannot be removed or inspected without prior removal of other equipment or parts.	GENERAL	Repositioning of equipment is required to avoid having first to remove other equipment causing obstructions.
	(*a*) Starter Panel components, radio gear has to be removed first.	Fighter	
	(*b*) Starter Relay, oxygen bottles have to be removed first.	L. Bomber	
	(*c*) Booster coil requires prior removal of wing root fillets.	Fighter	
	(*d*) Voltage Regulator, requires prior removal of control assembly equipment and components.	Fighter	
3.	CONTAMINATION OF EQUIPMENT AND CABLES		
	Electrical equipment is often positioned so that oil, fuel or hydraulic fluid contaminates it due to spillage or leaks, requiring frequent removal for inspection and cleaning. Cables thus contaminated deteriorate more rapidly and require replacement more often.	GENERAL	Consideration should be given to positioning the equipment above the run of fuel, oil or hydraulic fluid lines container, filter, etc.
	(*a*) Booster coil supply lead runs round lower part of cowling where fuel collects, thus becoming contaminated.	Fighter	Suggest that re-routing round the top half of the cowling would cure this.
	(*b*) Prop-feathering motor covered in oil.	H. Bomber	Requires repositioning.
	(*c*) Pulsometer pump dipping into spilled fuel collected in well on top of ventral tank causing early failure of pump.	Fighter	Drain holes for the wells on top of the tanks would cure this.
	(*d*) Starter panel requires constant cleaning due to contamination by leaking fuel.	Fighter	Repositioning is required.
	(*e*) Contamination of junction box occurs when hydraulic fluid spills during filling of hydraulic system.	Fighter	Drip tray would eliminate this.

Serial No.	*Design Defect*	*Type of Aircraft*	*Remarks*
4.	FAULTY POSITIONING OF EQUIPMENT		
	In some cases equipment required to be removed bodily before some minor item of inspection can be carried out, *e.g.*:—	GENERAL	It was found that in some cases only minor modifications to holding brackets would be sufficient to give greater degree of access required.
	(*a*) Starter and feathering solenoid switches, connections not fully accessible without prior removal.	Fighter	Ease of inspection would be assured if these were mounted horizontally or upside down.
	(*b*) Inertia switch, access to connections is partly blocked and made difficult by its being placed close to an airframe former.	Fighter	Modification of the bracket holding the switch so as to hold the switch clear of the former was necessary.
5.	PLUG AND SOCKET CONNECTIONS		
	(*a*) These have to be disconnected by means of a strap spanner on some types and a special type "C" spanner on later types. Where they are fitted in banks they are too close together causing difficulty in connecting and disconnecting. The coupling threads are too fine and damage due to cross threading often occurs.	GENERAL	Use of a strap or "C" type spanner is deprecated as these are not satisfactory tools and the use of special tools should be avoided where possible. A standard nut type of fitting would be better. Cross threading could be avoided by use of a coarser thread.
	(*b*) Damage occurs to the conduit and to the plug pin connectors where extra force has to be used to uncouple plugs which have become very stiff.	GENERAL	Use of an assembly which has the locking ring as part of the stronger member, that is usually the fixed plug or socket, would avoid the weaker member from being subject to undue strain resulting from force being used in uncoupling connections, the locking rings of which are very stiff. An extra length of sheath bound up against the plug ends of conduits where these are exposed to weather, etc., would ensure plugs and sheaths would remain moisture proof at their usual point of failure.
	(*c*) As a result of (*b*) above, conduit sheathing often parts from plug allowing ingress of moisture, water, etc., to the cable.		
6.	NAVIGATION LIGHTS		
	The filament lamp should be such as to be easily removed. The present transparent wing tips have to be removed to allow free access.	GENERAL	It should be possible to design a type of mounting which allows the lamp to be fitted through a wing access panel.
7.	JUNCTION BOXES		
	Positioned so that the lid is difficult to remove and when removed the connections and terminals are not easily inspected owing to difficulty regarding access. This applied particularly to the boxes in wing root and engine nacelle.	GENERAL	Suggest more consideration should be given to positioning so that work that involves junction boxes and the terminals they contain can be easily carried out.
8.	GENERATOR GROUND TEST		
	On aircraft where no ammeter or voltmeter is fitted a test point connection is required so that during engine ground tests the generator system can be tested.	Fighter	On this type of aircraft a long lead has to be taken from the test ammeter or voltmeter to a connection on the aircraft. A test set complete with leads and connection is required.
PART 5.—ARMAMENT			
1.	GUN INSTALLATIONS		
	(i) 20 mm. Hispano gun front mounting units of varying pattern requiring special tools in each case.	Fighters	Suggestions: (i) A standard type front mounting unit is required for all fixed gun installations.

Serial No.	*Design Defect*	*Type of Aircraft*	*Remarks*
	(ii) Method of attaching the gun access panels unsatisfactory. No standard method between aircraft types. Panels secured by screws require excessive time to remove and replace.	Fighters	(ii) Quick release fasteners of standard pattern should be used throughout or alternatively sliding or hinged panels, this would facilitate re-arming and reduce considerably the time taken for gun inspection on certain aircraft.
	(iii) Water and oil allowed to collect in gun wells in wing installation.	Fighters	(iii) Drain holes should be incorporated.
	(iv) Gun heaters should be repositioned, prone to damage at present.	Fighters	(iv) Gun heaters should be repositioned forward of present position.
	(v) Method of attaching bottom empty case chutes unsatisfactory.	Fighters	(v) Quick release pins should be fitted in lieu of the present screws.
2.	GUN TURRETS		
	(i) Components difficult to service due to confined space and inaccessibility.	Bombers	(i) Although this is an unavoidable feature, it could be partially remedied by designing cupola which is easily detachable.
	(ii) Individual components difficult to remove necessitating in many cases removal of other components before item required can be worked on.	Bombers	(ii) While it is appreciated that it is not possible to make all turret components freely accessible, it is desirable that components requiring maximum servicing should be given priority of accessibility when the turret is fitted to an aircraft, also an external plug and socket connection should be made to all electric components; this would simplify the removal of such components.
	(iii) Access to turret holding down bolts is difficult.	Bombers	(iii) Fairings, etc., screening these bolts should be fitted with quick release fasteners, the same applies for access panels.
	(iv) External electric socket to each turret independent of main aircraft supply required.	Bombers	(iv) This would enable the ground test of electric turrets to be carried out without interference with other trades.
	(v) Different nipple sizes used on lubrication points, nipples in many cases partially inaccessible.	Bombers	(v) Standard size should be used and position studied with turret fitted to aircraft.
3.	GUN SIGHTS		
	The vernier adjustment mounting used with the Gyro Gun Sight is difficult to adjust accurately.	Fighters and Bombers	Alternative methods suggested are: (*a*) Friction adjustment. (*b*) Knurled nuts on threaded adjusters. (*c*) Adjustment of optical system only.
	PART 6.—WIRELESS AND RADAR		
1.	MOUNTING OF POWER UNITS		
	(i) Inaccessibility of plugs, sockets, and securing bolts owing to the Power Units being fitted "backwards," *i.e.*, facing to port instead of starboard. Presumably the reason for this was to avoid the plugs being knocked out by the navigator's feet thereby causing a danger of fire due to sparking.	H. Bomber	(i) Suggest that removal of the Power Units would be simplified and speeded up if they were fitted facing starboard and a protective cover (secured with the wing nuts) fitted to prevent the plugs being accidentally knocked out.
	(ii) The position of the Power Units is such that the removal of the Air Mileage Unit cannot be effected unless the Power Units are removed first.	H. Bomber	(ii) Could be remedied by repositioning either the power unit or A.M.U.

Serial No.	*Design Defect*	*Type of Aircraft*	*Remarks*
2.	FITMENT OF T/R SETS		
	(i) Method of fitment generally is unsatisfactory.	H. Bomber	(*i*) to (*iv*) Suggest better positioning and better mountings required.
	(ii) Transmitter is difficult to remove and refit owing to a combination of its weight, type of fitment and the height at which it is fitted.		
	(iii) Receiver tends to strain against its mounting and vibration can cause it to knock against table.		
	(iv) Receiver extremely difficult to remove on its own. Transmitter has to be removed first whether it is required to be taken out or not. The alternative method of removing receiver from its case is bad as there is a risk of damaging receiver when carrying down the aircraft.		
	(v) Cables to plugs and sockets are too short and plugs and sockets have to be twisted through 90° and held down while equipment is removed.	H. Bomber	(v) Difficulty could be overcome by the use of longer cables.
3.	USE OF "W" PLUGS AND SOCKETS		
	The disadvantages of this method of connection are:—	GENERAL	Suggest a quicker method of connection be devised and use of plugs and sockets of the type with a bayonet type locking device instead of the finely threaded locking rings.
	(*a*) Liability of cross threading when working in poor light.		
	(*b*) Tendency of plugs and sockets to become dismantled when being removed.		
	(*c*) Seizure of plugs and sockets requiring the use of a strap spanner to remove them.		
4.	CABLES AND GENERAL WIRING		
	Difficult to follow in large aircraft due to them all being cleated together. It is difficult to change an individual cable for the same reason.	GENERAL	Wiring could be run at different levels on both sides of the aircraft, each level comprising a separate section, *i.e.*, Electrical, Instruments, Wireless, Intercom., etc.
5.	AERIAL CONNECTORS		
	Terminal type of co-axial connection to aerials is unsatisfactory.	GENERAL	Suggest that all aerial connections should be made by plugs and sockets.
6.	PROVISION OF POWER SUPPLIES FOR RADAR FUNCTIONAL TESTS		
	No power supplies are available to carry out functional test of the Radar Equipment. This means that a Petrol Electric Set has to be taken out in a pinnace for the daily inspection.	Flying Boat	If the Auxiliary Power Unit in the aircraft had a rotary convertor fitted to provide the necessary power supplies for testing the radar equipment servicing would be easy.
7.	FITMENT OF RADAR SCANNER FAIRINGS		
	The Radar Scanner Fairings (port and starboard) situated on the under surface of mainplane outboard have to be removed for the inspection of the scanner unit. They are secured by a row of hexagon headed 2B.A. bolts. Time taken by two men to remove is 1 hr. 40 mins.	Flying Boat	Time could be reduced by either fitting mushroom headed cowling screws, *i.e.*, 2B.A. mushroom headed screws or alternatively slotting existing bolts for fitting with a screwdriver. It is, however, suggested that a fairing of the size could have been made much simpler and easier for fitting and removal by using six "Dzus" fasteners for locating and mushroom headed screws for securing.

DISCUSSION

J. D. North (Boulton Paul Aircraft Ltd., *Fellow*): Serviceability and reliability had never been given any serious consideration by the customer as having a market value. Spectacular engineering, rather than sound engineering, was the factor which sold things and it was not confined to aircraft. To a large extent the customer would get what he asked for, and he had not been prepared to give proper weight to serviceability and reliability. From the figures put forward by the author it would be worth while spending more money on the design of aircraft and even on their production, and still provide something which, to the customer, would prove cheaper on the whole.

They knew little about the basic reasons for unreliability in mechanism; and it was remarkable that in the library of the Institution of Mechanical Engineers there was not a single reference under the heading "Reliability" to any paper or publication.

That ignorance would be cured partly by careful investigation, if the time and money were spent on it, but still more if there were a closer contact between the user and the designer, not only by way of visits by the service people, but also by allowing people from the drawing office to spend some of their time in service units, where they could see for themselves what happened. People learned things when they saw them, whereas they would never learn them fully by being told or by reading about them in reports, of which there were so many to-day that the world could hardly contain them.

The design of an aeroplane was the integration of a number of components which were produced by different people. First it must be operationally satisfactory, otherwise it was of no use. Secondly, it must be capable of being manufactured reasonably. If the drawing office were near the factory, that point was constantly brought home to the people concerned with design. The third element was accessibility and ease of maintenance; that was a condition which had to be satisfied, and it represented one more element of difficulty. Integration should take place at the stage of the first mock-up; if the customer wanted the luxury three months later of adding pieces of equipment and moving others about, the mere physical difficulty of getting them in entailed sacrifices in the original conception of the provision for maintenance. Whatever was done by way of educating people on provision for maintenance, he did not think they would ever have a satisfactory design of aircraft for maintenance unless they ensured stability in the arrangement of the equipment in that aircraft during the early stages of design. They must bring in the maintenance people at the beginning; it was no use relying on making modifications afterwards.

Contributed: It was as well to emphasise that reliability and ease of maintenance, although directed towards the same object, were two quite different things. If a piece of mechanism were thoroughly reliable then ease of maintenance in the sense of adjustment, repair or replacement was unimportant; therefore first priority should be given to ease of maintenance for those things which were thought to be least reliable. This was where real difficulty occurred. No form of extended tests seemed to be a substitute for what happened under service conditions, but even if it were, the design, and consequently the maintenance facilities, usually had to be settled at such an early stage that tests to ascertain reliability had not been done.

The extensive role which engineering judgment played in the process of design was sometimes not fully realised, hence the necessity of making available the right kind of education. To see a mechanism in use under service conditions and to see the troubles to which it gave rise was educational in the way that no secondhand admonitions could be.

It was perhaps not difficult to understand that since the value which was to be attached to reliability and ease of maintenance could not be measured in a way in which performance was measured, but could only be assessed in advance of extended experience, opinion about those qualities in the initial stages of a new type was subject to a greater degree of uncertainty, which perhaps accounted for the failure to give them due weight.

N. E. Rowe (British European Airways, *Fellow*): It might be possible to secure improvement in maintenance, and perhaps a marked improvement, by improved reliability and improved technique together. This could be done if they had knowledge of the "reliable

life" of the various components, ancillaries, etc.

There might be a parallel with what had occurred in the aeroplane itself. Maintenance, like "Topsy," had "just growed"; doubtless in the early days of flying it was vital to look over the aeroplane after each flight, and probably also before the next flight, to ensure its reasonable working condition. The pre-flight inspection had become a matter of tradition. In the early days also, it was necessary constantly to look at the inside of the aeroplane, in case anything had gone wrong. That again had become a tradition, and they still looked inside. Thus, they had periodical inspections.

Similarly, in the early days of flying there was great uncertainty about aerodynamics; things were built, changed and adjusted, and it was not until they began to use wind tunnels that they could really forecast. In two recent lectures before the Society—that by Mr. Edwards, and the Second Louis Bleriot Lecture—the point had been made that by proper and effective use of the wind tunnel it was possible very largely to forestall all the troubles in connection with aircraft control, stability, and so on, which had constituted such a bugbear in the early days. Just as, in connection with auxiliaries, main components, controls, and so on, they had tried to forestall troubles by design based on the correlation of theory and wind tunnel and full-scale experiments, so they should try to forestall maintenance difficulties. That might prove to be difficult; but he felt that some of the difficulties arose mainly from tradition.

G. R. Edwards (Chief Designer, Vickers-Armstrongs, Ltd. (Weybridge), *Fellow*): It was a good thing for the designing members of the fraternity to be spurred on occasionally to ensure that the aeroplanes they produced were in fact usable for most of their time, instead of being unusable.

One of the means of preventing aeroplanes going wrong was to leave off the bits which, from long practical experience, they knew did go wrong. In his experience of aeroplane servicing it was the working bits that went wrong and which had to be taken to pieces. So that the best way in which the designer could help the R.A.F. or civil operators in connection with the servicing of aeroplanes was to leave the working bits off! That might sound somewhat "advanced," but he felt that, before starting to put a lot of working bits on, it was a good idea to think carefully whether their addition was really going to pay a dividend. They should consider whether the gain in operational efficiency which would result from the addition of any part, would be outweighed by the loss which that addition would entail in respect of serviceability. He believed that from the ordinary type of aeroplane—by which he meant the 200 m.p.h., twin piston-engined, up and down type—lots of things which were now considered to be essential could well be left out, and that thereby it could be improved from the maintenance point of view without impairing its useful performance.

They read in the newspapers that there would be advanced jet aeroplanes in the Royal Air Force next week or never, according to the newspaper. Assuming that the former view were nearer the truth, he suggested that the Royal Air Force had seriously to consider whether those highly expensive aeroplanes—and they would be expensive—would be likely to give of their best if they were to be maintained by boys who were in the Royal Air Force for 18 months, an interlude in their normal life which they were not likely to take very seriously. He did not suggest that those aeroplanes would be frightful pieces of equipment to maintain, for it was up to the Industry to see that they were not; but he did urge that they represented a different proposition from the ordinary bread-and-butter, medium-performance, aircraft; that they were likely to need special treatment, treatment at least on the level of the skill of the people who made them.

He was completely "sold" on piston engine cowlings belonging to the airframe and staying on the airframe, not being attached to the engine in any way. The author had illustrated a cowling of that type, and he could see no logic whatever in the cowling hanging on the power unit.

He questioned the statement that unserviceability increased with increased flying hours, because his experience of the Royal Air Force overseas, in the Middle and Far East, was that the only way in which to keep an aeroplane serviceable was to fly it; aeroplanes standing on the ground there became unserviceable very quickly, and he suggested that on such stations the serviceability,

rather than the unserviceability, was proportional to the amount of flying.

He agreed with the author's views concerning the conditions applying to the men who were servicing aeroplanes, for it called for a great sense of duty for a man to remain in a cockpit at a temperature of, say, 140°F. for two hours in order to do a job properly, instead of trying to skimp it in half an hour.

Would the author indicate the way in which the introduction of turbine engines into aircraft had improved serviceability? His experience with turbine engines, both with and without propellers, had convinced him that the absence of vibration, which was always present with the reciprocating engine, would make a very big contribution to serviceability of the bits which normally went wrong. Electrical equipment particularly, which was very sensitive to vibration, might serve very much better in view of the smooth operation of turbine engines; was there any evidence in the Royal Air Force to support that view? If so, then he would suggest that the obvious thing to do was to throw away reciprocating engines and replace them by turbines, with or without propellers.

B. Kaiser: To what extent had "Time Study and Job Analysis" been used in determining the inspection schedules? Had they used the normal methods of analysis by means of the stop watch and effort rating, or had they estimated the time required to perform the various operations? He thought that estimated times would cause difficulty in view of the restricted space available for working and the various tradesmen employed.

Had the R.A.F. considered the use of suitably designed incentive schemes, not necessarily financial, for increasing the productivity of the tradesmen?

In regard to the application of *D.F.* and *D.S.* to particular units he thought that a major limiting factor in servicing was the number of aircraft which could be worked on at any one time; this depended not only on the number of men, but on the floor area available, and the latter was often the difficulty. Would the author explain how local limiting factors, such as this, were introduced in the general formula outlined in Appendix A?

He was glad that the problem of over-inspection or "Tinkeritis" on daily inspections had been studied, and that the aircraft was considered serviceable unless reported otherwise by the flying crew. He thought that there was an element of danger in this, but he would like to know how it worked in practice.

He thought the work described in the lecture showed that the R.A.F. were equally if not more so, conscious of the importance of high efficiency as their counterparts in industry.

Wing-Commander A. H. F. Murphy (Commanding the Air Ministry Servicing Development Unit): They did not time by means of a stop-watch in order to get the utmost out of the men. The accusation had been levelled at him that he had tried to introduce factory methods into the R.A.F.; he wished he could, for he had seen men working in warm factories and hangars and had sometimes compared their conditions with those of the R.A.F. men working in cold and damp hangars.

The practice was for a sergeant or corporal fitter to do a job of work himself first—for example, the removal of a generator from a power plant—using the tools which the R.A.F. provided. That sergeant or corporal would repeat the job a second and a third time, or more, until he had discovered the best and quickest method of doing it. If he found that a simple tool could be made on the station to do the job more quickly than previously, it was made, and a recommendation went forward concerning its use. The operation was described in a few simple words in the schedule or taken care of in the course of the basic training of the men. That sort of technique had been developed and was applied to all the operations which the mechanics, skilled and semi-skilled, were called upon to perform.

In addition, every effort was made to sequence the operations so that there would be the least interference between the trades, particularly in the congested parts of aircraft, such as cockpits, turrets, and so on. Each trade—electricians, armourers, riggers, and so on—evolved what it considered to be an ideal sequence for a particular job. Thus, five or six conflicting claims were submitted as to the best sequence in which to do the job; those claims were discussed and eventually they all arrived at a compromise and produced a schedule which was considered a reliable guide to the men who were called upon to do the work. Every

endeavour was made to take into account the conditions in which the men had to work.

S. Scott-Hall (P.D.T.D.(Air), Ministry of Supply, *Fellow*): Much advice had been offered to aircraft designers and doubtless it would be extremely valuable to them. It seemed to him that the people who really wanted as much, if not more, advice were the designers of instruments and radio equipment and he hoped that some of them were present. It was difficult to bring home those facts to them because many of them were really outside the aeronautical field and did not appreciate the conditions appertaining to aircraft and flight. It had been appreciated that it was vital that they should understand those conditions in order that the equipment would fulfill the specification from a performance point of view. The importance of bringing home to them the vital necessity of keeping weight to a minimum had also been realised. Reliability was yet another aspect to which their attention must be drawn.

Were the statistics quoted by the author all reported defects? He suggested that over and above the unserviceability dealt with in the paper, there was an enormous hidden wastage of man-power representing work on defects which were not in fact reported at all. Would S/Ldr. Harrop comment on this.

The aim should be to design for reliability. He had been inspired by the ideas of Mr. Rowe and thought that this line of attack would lead to a great reduction of effort on repair and servicing and the ability to give a trouble-free life between major overhauls.

Contributed: In drawing attention to the high proportion of "reported defects" per thousand flying hours attributable to instruments and radio as indicated by Fig. 43 of the paper, he would have included engines and power plants but for the fact that he assumed with Mr. Edwards that the introduction of the gas turbine would result in a major reduction of power plant unserviceability.

He understood from S/Ldr. Harrop's reply to Mr. Edwards that there was little evidence, as yet, on the influence of the gas turbine but that such data as he had been able to collect indicated little change in the amount or character of consequent unserviceability.

From the nature of the reply, he assumed that S/Ldr. Harrop was referring to defects *other* than those associated with the power plant itself, since obviously the nature of the defects associated with gas turbines would be different from those with reciprocating power plants. If his assumption here were correct, the answer was surprising, for from experience of flying in aircraft powered with gas turbines it would have seemed that fatigue effects on the structure generally were vastly reduced. If the author were referring to power plant defects after all, was it possible that his reply was influenced by the teething troubles on earlier jet engines? The recent sealed bench running on gas turbines would suggest a much better serviceability level than for piston types.

N. J. Hancock (Ministry of Supply, *Assoc. Fellow*): In the Aircraft Industry it was generally considered best to keep production and inspection staffs in completely separate teams; it appeared from the paper that the R.A.F. regarded each man as his own inspector. Why was that considered to be a good thing?

He was rather surprised by the weight of responsibility which the R.A.F. placed upon the non-commissioned officer, who appeared to combine the duties of foreman, progress man, inspector and record clerk. Could the author give some idea of the time required to train an N.C.O. to that degree of efficiency, and the time during which a man remained un-promoted as the result of that efficiency?

Was any comparison available, as the result of the Berlin Air Lift, between the turn-round times for aircraft serviced by the Industry and similar aircraft serviced by the R.A.F.?

Paper work should be reduced and simplified. The paper work for servicing a Mosquito weighed 9½ lb. As an example of the danger of giving the paper enthusiasts a free hand there was the case of the Airframe Log Book; in 1925 it weighed 16 oz., but after 10 years of peace time development it became 60 oz.; after struggling with such things through three years of war it was satisfactorily replaced by a card weighing one oz. What percentage of the staff in the R.A.F. were engaged on purely clerical duties, producing beautiful charts, schedules and record cards, and so on, and maintaining and filing them? It seemed to him that the records were stupendous and that the percentage of people working on them must be very high.

He endorsed the author's request for simplicity in regard to the attachments of panels, instruments, and so on, but it was worth while to point out that, although those things were reported on at the prototype stage, the man who decided was the Chairman of the Final Conference. That man was a R.A.F. Serving Officer. There were times when the design people were not quite so helpful as they might be; but if proposals were put forward at that stage, something was usually done about them.

The three-point mounting of panel instruments meant less broken lugs, less distorted and defective instruments and less bolts with which to fix them; to his knowledge chief designers had been asking for it for the past 25 years.

C. H. Robinson (B.O.A.C. Planned Maintenance Group): The principle of participation had been successful in his organisation and a series of charts, each an improvement on its predecessor, had been produced in the course of time. From the beginning the operatives were drawn into discussions and, with their co-operation, a report was produced and subsequently, a time chart. The operatives were encouraged to make suggestions for the further reduction of times, and, in fact, suggestions were made continually, so that there was a continual process of improvement.

It was appreciated from the start that the use of stop-watches would antagonise the men and experience had shown that the scheme adopted did appeal to them.

A. J. Brant (*Assoc. Fellow*): Because of the suggested shortage of man-power in the R.A.F., there was a rumour that the Industry would be called in to assist in major inspections of R.A.F. aircraft—independently of the Berlin Air Lift. How could the author's system be adapted to the work if it were undertaken by industry?

Would the author agree that his scheme had to bear very heavy overheads by way of supervision? In one schedule, for example, there was a team of approximately 18 operators actually doing the work, in addition to six supervising and inspecting N.C.Os. The author had appeared to indicate that one N.C.O. did all the supervising, but there appeared to be six of them, one for each trade, one of them being a sort of "head boy" who controlled the progress of the job. In addition to those supervisors there was the general administration. Thus the overheads seemed to be very heavy for the employment of 18 productive workers.

Would the author agree that, in order to enable the scheme to operate really successfully, it must be backed by another flexible organisation from which the rectification and modification gang could be called as required and then released when they were not wanted?

He suggested that the success of the scheme would depend on a planned input of work; and there was also the important point of the availability of supplies of spares and equipment. The finding of the right answer in regard to those matters was important to the R.A.F., and even more so to the Industry, if a scheme were to be successful; to ensure its smooth running there must be co-ordination of supplies of spares and equipment and the continued input of work, in order to avoid idle time—and it should be borne in mind that one per cent. of idle time in Industry gave rise to terrific consternation in management circles. Further, idle time not only worried the management, but also gave rise to demoralisation among the workers.

W. L. McAllister (de Havilland Aircraft Co. Ltd., *Assoc. Fellow*): Modifications arose with monotonous regularity, and the engineer officer or supervisor who had to fit them into the planned servicing graph had an unenviable task. When modifications arrived at a Unit they had already been given a man-hours time for embodiment, presumably by someone who had studied the work involved previously. As soon as a modification came to be initially embodied on a Unit, however, by labour unaccustomed to the incorporation of the modification, the man-hours, as laid down, had to be practically ignored as the personnel employed were unavoidably delayed by their own inexperience of the snags that arose. When the personnel had made the modification a sufficient number of times to ensure a convincing estimate of the man-hours required under local conditions, the particular modification was almost completed on the Unit and the engineer officer had another list of outstanding modifications on his hands.

Therefore it was impossible to work to the basic time in man-hours and this fact became an overwhelming bugbear to the engineer concerned, as he would be called upon to submit his timing figures to the people plotting the complete turn-round time graph.

In the basic layout of planned servicing, modifications instead of being considered as of major importance, seemed to have been relegated to the level of incidental repairs and their embodiment, within the structure of the scheme, left to the discretion of the Unit engineer officer. It was to be hoped that the planners at higher level would take a sympathetic view of the elasticity required for this section of the planned maintenance layout.

Air Marshal Sir Ralph Cochrane: Servicing based on formal inspections arose out of the premise that an inspection would bring to light defects and potential defects. If that premise should prove to be false—and he believed that some operators now were beginning to question it—they could perhaps see a different line of approach. They knew that moving parts would fail at some time as indeed might any piece of equipment, and in his Command they had been trying to find out the facts statistically, for if it were known when things were likely to go wrong, the system of maintenance could be brought into line with the facts. In the past, he believed, too few people had known the facts, and those facts had not been analysed sufficiently closely. Now that the facts were beginning to come to light it appeared that the formal servicing inspection, which was most efficiently done, did not in general indicate future defects or reduce their incidence. Therefore, was it worth doing? On two stations where they were experimenting they had more or less cut out the formal inspection. Naturally, they were keeping a very close eye on things.

In the Service it was necessary to envisage limited man-power and for some time to come limited skill, therefore that limited man-power and skill must be used to the best advantage, which he thought might well be for rectification rather than for inspection which experience suggested did little to reduce the number of defects occurring during flight.

W. S. Hollyhock (Hawker Aircraft Ltd., *Assoc. Fellow*): Would repair by replacement be a feasible proposition in wartime, for it would necessitate a considerable amount of replacement at the places where the aircraft were situated? During the last war, he believed, that had proved to be unattainable; spares were not available in sufficient quantities at the places where the aircraft were situated to enable repairs to be effected by replacement, and in any future war the same sort of thing might apply.

The fighter aircraft designer was asked to incorporate a "few ounces" of extra weight from time to time, but every department had its own few ounces that it wished to add, and the sum total was apt to be rather frightening, unless a firm stand was taken. For example, the author had mentioned that oil drainage was sometimes inadequate. That was true; but to supply a drain cock which was adequate for the quick draining of an oil system meant the addition of a considerable amount of weight. That was just one item out of a considerable number with which the aircraft designer had to contend.

The problem of maintenance and accessibility was two-sided.

Air Commodore G. F. Smylie: He supported the author's contention that reliability was the great requirement at the moment, and showed a graph (Fig. 47) representing a typical station's operation of aircraft over a year. At the top was a small area representing the number of aircraft undergoing periodical inspection; below that was an area representing repairs and modifications; a much greater number of aeroplanes being unserviceable due to that cause. Below that again there was an area for aircraft awaiting spares, and another relating to aircraft awaiting man-power. The really serious factor, however, was haphazard unserviceability—unserviceability on the flying field not discovered on inspection and not due to damage during flying or when on the ground, but caused by things becoming unserviceable during the flying life of the aircraft: this represented roughly 50 per cent. of the total number of aeroplanes unserviceable for all causes. The area representing aircraft awaiting spares was contributed to very largely by haphazard unserviceability. If this unserviceability could be overcome, the same task could be achieved with fewer aircraft. This would mean reduced capital expenditure and at the same time permit the limited man-power to be more usefully employed.

The graph, which showed the daily average aircraft state for a year, indictated for example that a number of aeroplanes had arrived on the station and that modification action had to be taken immediately; the amount of work on modification had increased correspondingly.

S. K. Reeves (A.I.D., Ministry of Supply): Could the author give some idea of the degree of confidence which the R.A.F. had in the data they collected, having regard to the fact that much of it was provided by junior operatives? For example, a lot of the information came from the entries on the record of servicing slips, entries on Form 700, and so on, but he wondered how much was allowed to pass unrecorded, how much was inaccurately recorded, and so on.

In planned servicing the N.C.O. in charge of any trade had not only to carry out the duties that a foreman performed in industry, but he had all sorts of other duties in connection with the supervision of the men under his control; he must see that the tools and equipment required were to hand; that his team was complete; he must collaborate with the N.C.O. in charge of servicing and bring in the rectification team at the right time and, in addition, he must carry out certain specific inspectional checks. As most of the men employed were in the Service for only a year or 18 months, and probably did not regard the experience as a very happy interlude, just how efficiently did the N.C.Os. in charge of trades carry out inspection, bearing in mind also the amount of other work they had to do?

One of the contractors with whom he was associated had found that the carrying out of the requirements of the planned schedules conscientiously had thrown up an enormous amount of rectification work. If the rectifications were done thoroughly, and if the inspectors used roving eyes with intelligence, a large proportion of the total time was spent in carrying out rectifications, repairs and adjustments which inspection had thrown up and consequently, the proportion of work which was actually planned decreased. He had gathered, however, that that was not so in the R.A.F., that they had not quite so much rectification to do and that generally, as soon as the planned schedule was completed, the whole servicing operation was finished.

How did the quality of the work done by contractors compare with that done by the R.A.F.?

T. N. Hainsselin (A.I.D., Hawker Aircraft Ltd.): Nowadays, during the prototype stage, a considerable amount of work was done by way of structural and vibration testing; could the information thus obtained be applied usefully by the Royal Air Force with a view to reducing servicing and maintenance?

A. H. C. Greenwood (*Assoc. Fellow*), *contributed*: Would S/Ldr. Harrop comment upon the effect of working conditions on serviceability, expressed in terms of recurrent unreliability and man-power expended? W/Cdr. Murphy mentioned working conditions, presumably at the A.M.S.D.U., Wattisham, and it would be interesting to know how the statistics obtained there compared with similar figures from the Winter Experimental Establishment at Edmonton, or the Tropical Unit at Khartoum.

H. G. Parker (*Assoc. Fellow*), *contributed*: The lecturer had shown the difficulty, if not the impossibility, of meeting a station commander's requirements of 75 per cent. serviceability but was not so willing to admit the difficulty of design teams in meeting the demands of servicing crews for "just a few more cocks here and there," and so on.

To mention only one point among the many that required solutions, servicing meant inspection panels, which in time meant fasteners.

Each "few ounces of isolating cock" asked for meant a hole from which to operate it (he glossed over the point that these extra cocks would in their time mean more inspection and more servicing). The requirements of this insignificant panel would include:

1. It must be large enough to allow operation and "locking open" of the cock.
2. It must be smooth and close-fitting in these days of high-speed and laminar flow.
3. It should be air-tight against disturbing pressure leaks.
4. If provided with only one fastener it must be stiff to obviate distortion.
5. If provided with several fasteners it would be more difficult for interchangeability.
6. It must be fastened to the structure to prevent loss—or damage by being trodden on.
7. If hinged then points 2 and 3 were made more difficult.
8. If hung by string or wire it would spin in the breeze at dispersal or on shipboard.
9. It must have good fasteners.

All ultimately hung on point 9, but in spite of all the manufacturers and all the official

approvals the really serviceable fastener had not yet been invented—let alone the perfect one.

SQUADRON LEADER HARROP'S REPLY

Mr. North: It was gratifying that Mr. North endorsed the points that it was cheaper in the long run for all concerned to invest in quality and that the maintenance people should be brought in at the very beginning.

He was glad to note Mr. North's point that no form of extended tests seemed to be a substitute for service experience. There was a wealth of experience in the R.A.F. to be had for the asking which was considerably cheaper than the expensive rigs and elaborate test gear required for simulating flight conditions. All this accumulated experience should be ploughed back into design, then maintenance would become relatively unimportant.

Mr. Rowe: Mr. Rowe had propounded a useful proposition with his simile of wind tunnel experience to gauge reliability of components. However, it was possible for tradition to creep into accepted data. The sparking plug was a good example; it had stuck at 200 hours running for far too long —it was almost the traditional life of a plug now, submerging the original aim "*to fit and forget.*" What had been good enough for the old types of aircraft was not good enough now, especially when it was realised that with some engine installations it was quicker to change the engine than change the plugs!

Mr. Edwards: The requirement for a superior mechanic to service the superior aircraft they hoped to see in the near future was being carefully studied. But the difficulty was that although they knew what they wanted, would the Treasury, which meant the taxpayer, be prepared to pay the superior mechanic what he was worth? At the same time it was wrong to suppose that R.A.F. aircraft were being maintained by conscripted boys—it was more a question of how much dilution of experienced personnel by N.S.A. men the R.A.F. could stand with safety.

Mr. Edwards had queried the general truth of the flying hour/unserviceability theory; while it was undoubtedly good for an aeroplane (as for a human being) to be continually exercised, above about 15 flying hours per aircraft per month the incidence of unserviceability was definitely related to flying effort, as was also the amount of spares required. The basic theory given in Appendix A ignored the element of unserviceability caused by climatic deterioration of idle aircraft.

Some false prophets had created pious hopes which were unsupported by the evidence available so far about the introduction of the turbine engine lessening the amount of servicing. Although it appeared that first line servicing of turbine engines was easier by virtue of the reduced number of defects, the man-hour cost was about the same as that for the piston engine, probably because diagnosis and accessibility of turbine defects were more difficult. At the same time the load of engine work in second line servicing had increased due, mainly, to more frequent removal of turbine engines for flame tube and blade inspection and reconditioning by manufacturers. It was rather alarming to find that the defect rate for the airframe and accessories had increased more than perceptibly, as shown by Fig. 48 which was an unsatisfactory small sample concerning only 1,000 flying hours in each case. Those increases appeared to be part of the price for increased speed. As many of the airframe defects (in the turbine aircraft) occurred with the landing gear, he would suggest that Mr. Edwards might well add this as one of the things which "went up and down," which should be shed in future, at least for some aircraft (like the German fighter ME.163) or it might be possible to replace the conventional gear with wheels in the belly.

Mr. Kaiser: Incentive schemes were so much a psychological question it was difficult to answer adequately. So much depended on morale, which depended on good leadership, management and training. It was the will to serve for its own sake that mattered. The satisfaction of doing a good job well, as a co-operative team, had its own rewards even though it often went unrecognised abroad. This sounded trite, but since a Commander had no control of financial or material awards, the solution was to make the job easier to accomplish by close attention to the details and difficulties of the job, which was the essence of good management. Also, he had found that if the job were made interesting and competitive, airmen would voluntarily work hard and late in order to beat a justifiable target—this had happened all the time with the Berlin Air Lift.

Other limiting factors, such as the amount

of hangarage, should be taken into account in formulating the "plan." More often the limiting factor was not technical but domestic, such as the amount of air crew living quarters or number of cooks (to feed the servicing personnel) available on the station. Hangar space became relatively less important as the "turn-round" time of unserviceable aircraft was reduced. In the general formula in Appendix A (para. 21) it had been assumed that man-power was the chief limiting factor related to the planned number of aircraft "on the floor" (para. 26). If, however, the floor space were a limiting factor, there would always be some time spent by the aircraft awaiting hangar space (if essential for servicing). Assuming that the floor space occupied by aircraft "awaiting spares" could not be used, then the general theory for serviceability, y became less,

i.e. $$y=\frac{F+D}{F+M+S+D+H}$$

when H = number of days the aircraft was awaiting hangar space. If however the floor space occupied by aircraft awaiting spares could be used by leaving them outside, y then became

$$y=\frac{F+D}{F+S+D+(H \text{ or } M)}$$

depending on whichever was the greater value, H or M.

Mr. Kaiser's reference to "Tinkeritis" during daily inspection was an apt description of this element of servicing. In practice the limited daily inspection worked well, provided that the air crew were fully aware of their responsibility for fully reporting the behaviour of the aircraft on the last flight. For long flights it had been found necessary to introduce a captain's report form. A lot of unnecessary ground running of engines had been eliminated by these means.

Mr. Scott-Hall: He agreed with the remarks about the designing of instruments and radio equipment. If they would consider them as "allied to," rather than "auxiliary to," the Aircraft Industry, they might become more conscious of their responsibility for ensuring trouble-free aircraft and flight.

There were a large number of defects which were not reported. They were mostly small ones with which the percentage of time represented by diagnosis, collecting tools and spares, subsequent adjustment and ground test was very great in relation to the amount of rectification work done—*i.e.* the total turn-round time for the aircraft was expensive for petty defects, such as a slight leak in a hydraulic or pneumatic system. Only an elaborate administrative machine involving a prohibitive overhead could record all that went on at Unit level. *Ad hoc* research indicated that the actual defect rate was two to three times greater than that reported through the usual channels, whereas the man-hour cost was about double, due to the unreported diagnosis and test times, etc. The best that could be done in the circumstances was to examine the aircraft utilisation rates and servicing man-hour per flying hour costs, then search for the reasons for low dividends.

He had replied to Mr. Edwards that although the reduced vibration of turbine engines must have a beneficial effect on the airframe and its accessories, this was not apparent from the figures obtained so far. The increased operating height and speed of the turbine-engined aircraft seemed to him to be the basic cause of the increased airframe defects. For example, the landing speeds were far higher for the turbine aircraft, undercarriages, brakes and wheels suffered accordingly. they had only to fly through a rain storm to spoil the surface finish which required a great deal of labour to repair it. and pressurisation of cockpits had also introduced new troubles. The faster aircraft were much more sensitive to weaknesses in design.

Mr. Hancock: The R.A.F. had frequently experimented with the idea of "separate inspection" for first and second line servicing (third and fourth line inspection was similar to that in the Aircraft Industry) but had come to the conclusion that for operational flexibility and economy of personnel it was better not to have separate inspection and servicing teams. The N.C.O. tradesman was essentially both a supervisor and an inspector. The inspection part of his duties, in a sense, was done separately and independently of the workman (the subordinate tradesman) but was done progressively through the job, which had obvious advantages. Also, N.C.O. members of a servicing team got to know their men intimately and were more aware of what was going on during each phase than if they were called in separately to inspect the work. The success of this kind of quality control however, depended on the training and selection of N.C.O.s

In general it might be said that the tradesman was serving his apprenticeship to become an N.C.O. up to the rank of Corporal when he reached the peak of his skill. Thereafter his training was mainly for supervision and control of work. Therefore the promotion of a tradesman depended on his display of skill, trade knowledge and qualities of man management, in that order, through the various ranks. The average time to progress through the ranks depended on the fluctuating contraction and expansion of trades from time to time. The great difficulty from the career point of view was to get the correct balance between different types of tradesmen who could not be sacked or made to change their trade if they were no longer wanted in the Service. These problems were being actively investigated to try and find solutions.

As to the R.A.F. *versus* Industry in respect of planned inspection times in support of the Berlin Air Lift, the R.A.F. had done far better in turn-round time, being able to turn the aircraft round two to three times as fast as could the Industry; so they should, for they had far more experience of the work and were not hampered by fixed working hours or tied to bus times as was the Industry. He was not able to judge the respective qualities of the work because to get a fair comparison it would be necessary to examine the defect rate of the individual aircraft throughout their flying cycles. But those done by the Industry looked better and cleaner than those done by the R.A.F.

Surprisingly, the overheads that had been introduced in order to make the Planned Servicing System work were quite small. The overheads represented by the paper work, without the planned servicing scheme, represented about one per cent, for a Unit of say, 400 technical personnel, with considerable hidden wastage consisting of N.C.O.'s time in separately working out their own time-tables. With the introduction of the new scheme the wastages were stopped, since all control was centralised in the one department which called for an increase in overheads for the same size of Unit of only another one to two per cent., depending on the complexity of the aircraft and consequently the technical documentation. This small increase in overheads was amply compensated by the reductions, about 15 per cent., that could be made in all the servicing departments.

There was a balance to be struck between being submerged by paper work or getting into a chaotic muddle without it.

Mr. Brant: Mr. Brant had raised an important point with regard to the possible integration of the Industry with the R.A.F. to assist with major inspections. He had tried to show how the importance of the major inspection had been reduced by bringing its turn-round time down to controllable limits and also how the arisings were affected by the length of the major cycle and the aircraft wastage rate. Therefore, in his opinion, it would be a great help to the R.A.F. and to the Aircraft Industry, if they could push major inspections back, say, to 1,000 hours, because if "majors" were thrown up at such intervals he believed it would be more economic for the Industry to do them and, incidentally, help the Industry to see how their products had behaved in the Service.

He was sorry that the paper did not clearly show the detail composition of servicing teams, but Mr. Brant had interpreted correctly in assuming one N.C.O. (generally a Flight Sergeant or Sergeant, depending on the size of the team) to be in charge of the whole team, assisted by subordinate N.C.O.s who were responsible for the work of their particular trade from the specialist angle. One specialist N.C.O. might, however, be supervising the same work in two or three teams. It depended on the amount of work. Although for the purposes of a servicing schedule each N.C.O. in the team was specified, establishments might show .5 of an N.C.O. for each of two teams, .3 for each of three teams and so on.

He had indicated in the paper the necessity for a mobile labour force to cater for the unpredictable work. They were deployed wherever they were most needed.

The R.A.F. tried to plan the input of work by means of "stagger charts" which must be co-ordinated; for example, power plants had generally a stated life, and from the charts the progress could be seen of an aircraft towards a power-plant change and arrangements could be made for the spare power plant, spares, equipment and personnel accordingly.

Mr. McAllister: All modifications were done in order of priority, those affecting safety of flight were done first. This work was classified with the unpredictable work because not only were they unpredictable in

extent and incidence, but also because they depended on the bits and pieces being available at the right time. Therefore their embodiment must be left largely to the discretion of the Unit Engineer Officer. The most important thing was ensuring that the work involved was catered for in the establishments.

Mr. Hollyhock: The policy of repair by replacement was only committed to those items, such as engines, tyres, magnetos, flame tubes, brakes, instruments, radio sets, generators and the like which could be predicted with certainty as recurring requirements. This meant more decentralised stocks at the places where the aircraft were situated. The alternative to this policy was a larger aircraft establishment to compensate for the prolonged turn-round time associated with "repair *in situ*." It was obviously cheaper to provide the spares than complete aircraft. Whatever servicing policy was adopted, there was always a percentage of aircraft grounded for lack of spares through under-provisioning in the first place, which had to be compensated by providing additional aircraft in the establishment. Line "C" of Fig. 45 and item 32 of Appendix B indicated how this prime cost was related to the rate of effort which depended, *inter alia*, on reliability. In any case no one could forecast the number and range of spares required to repair accidental damage or that caused by enemy action. The whole problem of spares provisioning and distribution was imponderable and still far from solution in the R.A.F.

Although he sympathised with designers that ruthless weight control must be exercised in design, control was not always exercised in the right direction; careful examination of Appendix D would show that, with few exceptions, the demand for easier maintenance could be met without impairing the performance requirements in the slightest. For example, with fuel tanks a larger orifice would allow the stack pipe of a tanker to enter the aircraft tank to facilitate draining the tanks—in one case it took eight hours to drain 1,500 gallons of fuel via the outlet pipe of the tank.

He agreed that the problem of accessibility in fighters was formidable. If accessibility could not be obtained, then reliability became relatively more important.

Mr. Reeves: Much depended on the N.C.O.s in charge of jobs for the accuracy of data on running times, and so on. Repair by replacement facilitated the means, because all such replacements must be recorded on the Form 700, whereas the cause of breakdown of the component could be recorded separately by the component servicing personnel. The records for second, third and fourth line servicing were fairly accurate because they were more static in that degree, but because of the mobile and fluid nature of first line servicing the recording, in some respects, was open to suspicion for the reasons already given to Mr. Scott-Hall.

It was not true that the R.A.F. did not find a lot of rectification work to do during inspections. The extent to which this work prolonged the turn-round time depended on how well it could be phased in with the inspection plan. He thought the N.C.O. inspectors were allowed greater discretionary powers than their A.I.D. counterparts in the Industry, which probably accounted for some of the differences in the amount of rectification work. He thought the contractors had taken to the scheme extraordinarily well.

Mr. Hainsselin: Any efforts to reduce maintenance by tests in the prototype stage were well worth while. Vibration tests should be able to throw some light on to the expected reliability of electrical gear, instruments and radio equipment.

Mr. Greenwood: He had no knowledge of servicing figures for the Units at Khartoum and Edmonton. He assumed that Mr. Greenwood meant a comparison with the hot and cold extremes. Actually A.M.S.D.U. produced average times for temperate conditions which would be allowed for in raising task charts according to local weather factors. Units in the Middle East were working quite happily to the servicing schedules produced by A.M.S.D.U.

Mr. Parker: He had covered Mr. Parker's point about inspection panels in the paper, but agreed about the need for a really foolproof fastener.

THE ROYAL AERONAUTICAL SOCIETY

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

EIGHTY-FOURTH ANNUAL REPORT OF THE COUNCIL 1948—1949

IN the January 1949 issue of the JOURNAL a summary of the Society's activities for January - December 1948 was given. In that summary the Note by the President on the work of the Society, which Dr. Roxbee Cox wrote in March 1948, was reprinted in full. In it the President drew special attention to the first of the Statutes of the Society, that it exists for the advancement of Aeronautical Science and Engineering.

On 22nd December 1948 there was read at the Board of The King's Most Excellent Majesty in Council a Report of a Committee of the Lords of His Majesty's Most Honourable Privy Council, in the words following:—

"Your Majesty having been pleased, by Your Order of the 2nd day of June 1948 to refer unto this Committee the humble Petition of H. Roxbee Cox, Esquire, and others praying for the grant of a Charter of Incorporation to the Royal Aeronautical Society.

"The Lords of the Committee, in obedience to Your Majesty's said Order of Reference, have taken the said Petition into consideration, and do this day agree humbly to report, as their opinion, to Your Majesty, that a Charter may be granted by Your Majesty in terms of the Draft hereunto annexed."

His Majesty ordered "that the Right Honourable James Chuter Ede, one of His Majesty's Principal Secretaries of State, do cause a Warrant to be prepared for His Majesty's Royal Signature, for passing under the Great Seal a Charter in conformity with the said Draft."

On the 17th of January 1949 the Charter of Incorporation was signed and the Royal Aeronautical Society became a Body Incorporate. The full text of the Charter of Incorporation was published in the February 1949 issue of the JOURNAL.

There is every indication that the steady growth of the Society which has culminated in the granting of this Charter is continuing and the influence of the Society is extending.

In the JOURNAL for January 1949 there was put on record such parts of the monthly notices and other information of the Society's activities which should be permanently recorded.

COUNCIL—1948-49

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Royal Society—International Union of Theoretical and Applied Mechanics: Professor A. A. Hall.
Royal Society of Arts—Conference on the proposed 1951 Exhibition: Sir Frederick Handley Page.
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Institution of Electrical Engineers—Committee on Radio Equipment for Civil Aircraft: Mr. C. H. Jackson.
Institution of Mechanical Engineers—National Certificates and Diplomas in Mechanical Engineering: Professor F. T. Hill and Sir Frederick Handley Page.
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National Central Library: Mr. J. E. Hodgson (Honorary Librarian).
University of London—Faculty of Engineering Special Committee: Mr. W. G. A. Perring and Mr. R. S. Stafford.
Regional Advisory Committee for Mechanical Engineering: Sir John S. Buchanan.

MEMBERSHIP

During the year 1948 the membership of the Society continued to increase, a fact which is particularly encouraging in view of the necessary increases in annual subscriptions which had to be made to meet the rising costs. This steady increase in membership is all the more encouraging in that it reflects the growing importance of the Society in the scientific and engineering sides of aeronautics.

During the year the Council agreed, under Rule 18, that any member of the Society who had been a member for not less than 25 years and had retired from regular employment might continue as a member with full membership rights (other than the right to receive copies of the JOURNAL) without further payment of annual subscription. Such members would receive copies of the JOURNAL on payment of a subscription of £1 11s. 6d. per annum.

STATE OF MEMBERSHIP, 31st DECEMBER 1948.

Grade	Paid Members		Life and Hon. Members		Suspended Members		Totals	
Fellows	364	(356)	39	(36)	5	(3)	408	(395)
Associate Fellows ...	2315	(2032)	11	(11)	66	(39)	2392	(2082)
Associates	2100	(2009)	6	(4)	173	(120)	2279	(2133)
Graduates	824	(675)	—	(—)	31	(29)	855	(704)
Students	1021	(1111)	—	(—)	89	(88)	1110	(1199)
Founder Members ...	15	(15)	1	(1)	2	(2)	18	(18)
Companions ...	189	(212)	9	(7)	33	(27)	231	(246)
Temp. Hon. Members	——	(——)	34	(35)	—	(—)	34	(35)
	6828	(6410)	100	(94)	399	(308)	7327	(6812)

(Figures in brackets are December 1947 figures.)

ANNUAL GENERAL MEETING

The Annual General Meeting of the Society, held on Friday, 7th May 1948, was reported in the JOURNAL for January 1949. At this meeting the list of Fellowship Elections for 1948 was announced.

PRESIDENT

Dr. H. Roxbee Cox, B.Sc., D.I.C., F.I.Ae.S., F.R.Ae.S., was elected President of the Society to serve from 1st October 1947 to May 1949.

VICE PRESIDENTS

The following were elected Vice-Presidents of the Society to serve from 1st October 1947 to May 1949.

Sir John S. Buchanan, C.B.E., A.M.I.Mech.E., F.R.Ae.S.
W. G. A. Perring, Esq., F.R.Ae.S.
N. E. Rowe, Esq., C.B.E., B.Sc., D.I.C., F.R.Ae.S.

TECHNICAL COMMITTEES

The past year has continued to show an increase in the activities of the technical sub-committees under the general supervision of the Technical Committee of the Council. The full number of data sheets issued by the Structures Sub-Committee is now 123 and well over 300 sets of sheets have been sold. The Aerodynamics Sub-Committee have issued 68 sheets and close on 400 sets have been sold. The sheets are issued to government establishments, firms and individuals at home and abroad and now that they have been reprinted it is hoped to increase considerably the number sold.

The Materials Sub-Committee have sponsored the issue of monographs to give a presentation of the state of the art, as it was not found possible to issue information on materials in the form of data sheets. The first monograph, by Major P. L. Teed, is now in the hands of the printer and it is hoped will be published during 1949. A number of other monographs have been under consideration.

Similar monographs for Instruments and Equipment are being sponsored by the Instruments and Equipment Sub-Committee and four monographs are in active preparation.

The Aeroelasticity Sub-Committee also have under consideration monographs, and the Hydraulics Sub-Committee text books on Aeroplane Hydraulics, and Aeroplane Pneumatics.

During 1948 considerable progress was made with the preparation of data sheets on Performance by the Performance Sub-Committee and on Fuels and Oils by the Fuels and Oils Sub-Committee, a joint committee with the Institute of Petroleum. It is hoped that the issue of data sheets on both subjects will begin in 1949.

Following extensive inquiries during the year into the support likely to be forthcoming from the Society's members the Council agreed to the Technical Committee's recommendation to publish *The Aeronautical Quarterly* containing papers of a high scientific standard on any subject related to aeronautics, making an original contribution to aeronautical science, or developing methods of analysis or experimental techniques. The first issue was published in May 1949.

The increase in the Society's technical activities has involved an increase in expenditure. Of the expenditure for 1948 a little less than half was borne by the Society itself and just over half by grants from the Ministry of Supply and the Society of British Aircraft Constructors. The Council take this opportunity of expressing their grateful appreciation of the assistance given to them by the Ministry and the Industry.

DIVISIONS

During the year the Council decided to form Divisions of the Society abroad. It was felt that if these Divisions could be formed with all the powers of the main Society in Great Britain save that of election to membership, members in each area would be enabled to keep more closely in touch and could themselves form Branches similar to those formed in this country.

The Council have pleasure in announcing that Divisions have now been formed in South Africa, Australia and New Zealand and in due course reports of their activities will be published from time to time in the JOURNAL.

The Council feel that the step they have taken to form Divisions is one which may have a considerable influence on the world-wide prestige of the Society and they look forward confidently to the formation of other Divisions as the need arises.

BRANCHES

In the January 1949 JOURNAL a list of Branch Lectures and Activities for 1948 was given.

This year the first of the Society's main lectures to be read under the auspices of a Branch was read by Dr. E. W. Still on " Some Aspects of Power Plant Development " on 6th October 1948 at Birmingham, with the President of the Society, Dr. H. Roxbee Cox, in the Chair. It is hoped that at least one main lecture each session will be read at a Branch centre.

GRADUATES AND STUDENTS SECTION

The Section had an active year during which ten technical meetings were held and six visits were made, the average attendance at meetings and visits being well above that of previous years. Particulars of these lectures and visits were published in the January 1949 JOURNAL, together with the names of the Committee and Officials of the Section.

RECEPTIONS

On the 17th and 24th of January 1948 the President, Dr. H. Roxbee Cox and Mrs. Roxbee Cox, supported by the Council, held receptions at the Society's Headquarters to give members an opportunity of seeing for the first time the remarkable Cuthbert-Hodgson Collection which was presented to the Society by Sir Frederick Handley Page towards the end of 1947.

A full report of the Receptions appeared in the January 1949 JOURNAL.

FINANCE

The Income and Expenditure Accounts and Balance Sheets of Aerial Science Ltd. and Aeronautical Trusts Ltd. for 1948 are published with this report.

OFFICERS AND COMMITTEES

The Council wish to place on record their appreciation of the work which has been done by the Honorary Officers of the Society during the year.

Captain C. F. Uwins, F.R.Ae.S., the Honorary Treasurer, has given invaluable advice and help on financial matters.

Mr. J. E. Hodgson, Honorary Librarian for so many years, has again during the year 1948 continued to advise the Society on all matters pertaining to the Library.

The Council wish particularly to place on record their appreciation of the work of the various Committees. The work being done by certain of the Committees has involved many meetings during the year and the results which they have achieved will prove of great value to the Society.

THE ROYAL (Aerial

Balance Sheet

£ s. d. 1947 Figures		£ s. d.	£ s. d.
	Share Capital—		
	Authorised—		
	20 Shares of 1/- each	1 0 0	
	999 Shares of £1 each	999 0 0	
		1000 0 0	
19 0	*Issued*—19 Shares of 1/- each fully paid ...		19 0
	Revenue Reserves—		
	Publications Development Account—		
6187 19 4	Balance as at 31st December 1947	6187 19 4	
	Income and Expenditure Account—		
9257 13 7	Balance as at 31st Dec. 1947 £8212 5 4		
1045 8 3 (Excess)	*Add*—Surplus of Income over Expenditure for year to date 870 10 5	9082 15 9	15270 15 1
	Current Liabilities—		
6168 6 3	*Sundry Creditors*	6486 16 5	
2184 12 3	*Subscriptions and other amounts received in advance*	2255 0 0	8741 16 5
£22754 2 2			£24013 10 6

H. ROXBEE COX, *President.*
C. F. UWINS, *Hon. Treasurer.*

REPORT OF THE AUDITORS TO THE

We have obtained all the information and explanations which to the best of our knowledge and belief were so far as appears from our examination of those books. We have examined the above Balance Sheet and annexed of our information and according to the explanations given us the said accounts give the information required by the Company's affairs as at 31st December 1948, and the Income and Expenditure Account gives a true and fair view

We have also examined the annexed Group Accounts comprising the Balance Sheets and Income and Expenditure properly prepared in accordance with the provisions of the Companies Act, 1948, so as to give a true and fair view of such Group Accounts so far as concerns members of Aerial Science Ltd.

3 Frederick's Place, Old Jewry, London, E.C.2.
23*rd March* 1949.

Income and Expenditure Account

£ s. d. 1947 Figures		£ s. d.	£ s. d.
	To Establishment Expenses—		
	Ground Rent, Heating, Lighting, Insurance		
1509 0 8	and Repairs		1330 17 10
	„ Office and Staff Expenses—		
7133 17 5	Salaries	6960 8 10	
803 13 1	Staff Pension Premiums	336 19 10	
1565 3 6	Printing and Stationery	1512 16 1	
1057 13 8	Postages and Telephone	1042 12 9	
— — —	Office Equipment	266 18 6	
959 16 3	Other Charges	1530 19 5	11650 15 5
11520 3 11			
	„ JOURNAL and Sundry Publications—		
11517 19 3	Printing Costs	13057 3 3	
990 4 11	Postages	1020 6 2	
1953 7 0	Other Charges	2652 18 2	
14461 11 2		16730 7 7	
3595 19 4	*Less*—Sales 3904 13 4		
10179 0 0	Advertisement Revenue... 8920 15 0	12825 8 4	3904 19 3
686 11 10			
	„ Expenditure on Data Sheets, *less* amounts		
1894 6 5	recoverable		2594 19 11
1083 1 9	„ Cost of printing List of Members		— — —
396 17 8	„ Meetings		541 18 3
	„ Library Expenses (including £2084 18s. 6d.		
711 2 0	written off Printed Books, etc.)		2890 18 9
131 18 6	„ Branch Expenses		228 9 6
163 15 3	„ Prizes and Donations		125 14 10
239 16 8	„ Dinners and Receptions		689 4 5
195 3 0	„ Audit Fee	78 15 0	
	„ Legal and Professional Charges	112 11 9	191 6 9
	„ Balance, being Surplus of Income over Expenditure for year, carried to Balance Sheet ...		870 10 5
£18531 17 8			£25019 15 4

AERONAUTICAL SOCIETY
Science Limited)

31st December 1948

£ s. d. 1947 Figures		£ s. d.	£ s. d.
	Printed Books, Bindings, Old Prints, etc., at cost less amounts written off—		
50 0 0	Written down value as at 31st December 1947	50 0 0	
— — —	Additions during year at cost	2084 18 6	
		2134 18 6	
— — —	*Less*—Amount written off during year	2084 18 6	50 0 0
	Investment in and amount due from Subsidiary Company—Aeronautical Trusts Ltd.—		
1 1 0	21 Shares of 1/- each fully paid at cost ...	1 1 0	
3696 1 0	Amount due from Royal Aeronautical Society Endowment Fund	2682 0 10	2683 1 10
	Current Assets—		
	Investments at cost—		
	£2335 10s. 7d. 2½% Funding Loan, 1956/61	2201 4 2	
	£4550 3% Savings Bonds, 1960/70 ...	4550 0 0	
	£1050 3% Savings Bonds, 1965/75 ...	1050 0 0	
7801 4 2	(Market Value 31st December 1948, £8192)	7801 4 2	
1 0 0	*Stock of* JOURNALS *and other Publications*	1 0 0	
7968 11 7	*Sundry Debtors*	7483 17 0	
75 10 1	*Payments in Advance*	113 0 1	
3160 14 4	*Cash at Bank and in Hand*	5881 7 5	21280 8 8
£22754 2 2			£24013 10 6

MEMBERS OF AERIAL SCIENCE LTD.

necessary for the purposes of our audit. In our opinion proper books of account have been kept by the Company Income and Expenditure Account which are in agreement with the books of account. In our opinion and to the best Companies Act, 1948, in the manner so required and the Balance Sheet gives a true and fair view of the state of the of the surplus of income over expenditure for the year ended on that date.
Accounts of Aerial Science Ltd. and of Aeronautical Trusts Ltd. In our opinion the Group Accounts have been the state of affairs and surplus of income over expenditure of Aerial Science Ltd. and its subsidiary dealt with by

(*Signed*) PRICE, WATERHOUSE & CO.

for the Year ending 31st December 1948

£ s. d. 1947 Figures		£ s. d.	£ s. d.
13747 3 0	By Annual Subscriptions		19974 16 0
250 0 0	„ Donations		574 10 0
122 14 6	„ Interest on Investments (Gross)	122 14 6	
57 0 2	„ Interest on Investments (*less* Tax)	57 0 2	
— — —	„ Income Tax recovered 1946/47 and 1947/48 ...	80 15 3	
	„ Interest on Endowment Fund Investments (*less*		
3142 15 7	expenses)	3797 3 1	4057 13 0
3322 10 3			
	„ Examinations—		
844 13 0	Fees received	939 16 0	
677 16 10	*Less*—Expenses	526 19 8	412 16 4
166 16 2			
1045 8 3	(*Excess*)		
£18531 17 8			£25019 15 4

AERONAUTICAL

Balance Sheet

	£ s. d.	£ s. d.	£ s. d.
Share Capital—			
Authorised—40 Shares of 1/- each		2 0 0	
Issued—21 Shares of 1/- each fully paid ...			1 1 0
Royal Aeronautical Society Endowment Fund—			
Capital Account—Balance at 31st December 1947 ...		129304 9 5	
Add—Donations received during year		17 8 0	
Entrance Fees received during year		1377 16 0	
		130699 13 5	
Income Account—Accumulated Surplus at 31st December 1947		5799 17 3	136499 10 8
Pilcher Memorial Fund—			
Capital Account—As at 31st December 1947 ...		99 14 0	
Income Account—Balance at 31st December 1947 ...	63 12 4		
Add—Income for year to date	5 7 4	68 19 8	168 13 8
Usborne Memorial Fund—			
Capital Account—As at 31st December 1947 ...		109 2 5	
Income Account—Balance at 31st December 1947 ...	74 14 0		
Add—Income for year to date	5 19 4	80 13 4	189 15 9
Herbert Akroyd Stuart Fund—			
Capital Account—Balance at 31st December 1947 ...		688 19 0	
Add—Profit on Realisation of Investment		2 10 0	
		691 9 0	
Income Account—Balance at 31st December 1947 ...	489 1 5		
Add—Income for year to date	38 7 2	527 8 7	1218 17 7
R.38 Memorial Fund—			
Capital Account—Balance at 31st December 1947 ...		978 3 10	
Add—Profit on Realisation of Investment		3 10 0	
		981 13 10	
Income Account—Balance at 31st December 1947 ...	776 7 5		
Add—Surplus of Income over Expenditure for year to date	33 15 5	810 2 10	1791 16 8
Edward Busk Memorial Fund—			
Capital Account—As at 31st December 1947 ...		449 6 1	
Income Account—Balance at 31st December 1947 ...	218 18 10		
Add—Surplus of Income over Expenditure for year to date	4 6 1	223 4 11	672 11 0
Wilbur Wright Memorial Fund—			
Capital Account—As at 31st December 1947 ...		2136 17 11	
Income Account—Balance at 31st December 1947 ...	194 10 4		
Add—Surplus of Income over Expenditure for year to date	13 3 10	207 14 2	2344 12 1
Simms Gold Medal Fund—			
Capital Account—Balance at 31st December 1947 ...		524 15 9	
Add—Profit on Realisation of Investment		3 0 0	
		527 15 9	
Income Account—Balance at 31st December 1947 ...	37 14 9		
Add—Surplus of Income over Expenditure for year to date	10 8 2	48 2 11	575 18 8
Alston Memorial Fund—			
Capital Account—As at 31st December 1947 ...		245 6 0	
Income Account—Balance at 31st December 1947 ...	53 8 1		
Add—Income for year to date	12 6 4	65 14 5	311 0 5
Carried forward			£143773 17 6

TRUSTS LIMITED

31st December 1948

Cash in Hand				1 1 0
Royal Aeronautical Society Endowment Fund—				
Leasehold Property at Cost—*Less* amounts written off	£ s. d.			
4, 8 and 9 Hamilton Place, at cost	12120 16 6			
Less—Amortisation written off to date	4845 16 6	7275 0 0		
Furniture at cost, *less* depreciation—				
At cost as at 31st December 1947	4275 0 9			
Additions during year	295 4 3			
	4570 5 0			
Less—Depreciation written off to date	2030 13 3	2539 11 9		
Investments at Cost—				
£21081 19s. 1d. 3½% Conversion Stock	21698 2 7			
£87235 12s. 5d. 3% Savings Bonds, 1965/75	87801 17 2			
£1000 2½% Defence Bonds	990 0 0			
£7912 11s. 3d. British Transport 3% Guaranteed Stock, 1978/88	6325 6 0			
£3935 12s. 11d. (including £3900 40% paid up) Trinidad 3% Inscribed Stock, 1967/71 ..	1660 0 0			
£1000 Associated Portland Cement Manufacturers' Ltd. 5½% Preference Stock	1723 11 6			
£1100 J. & J. Colman Ltd. 5% Preference Stock ..	1771 1 6			
£900 Lever Bros. & Unilever Ltd. 7% Preference Stock	1875 1 6			
£1200 Morgan Crucible Co. Ltd. 5% Second Preference Stock	1757 16 6	125602 16 9		
(Market Value 31st December 1948, £129087, including the 2½% Defence Bonds (unquoted) at cost.)				
Cash at Bank		3583 7 6		
Amounts due for refund of Income Tax ...		180 15 6		
		139181 11 6		
Less—Amount due to Aerial Science Limited...		2682 0 10	136499 10 8	
Pilcher Memorial Fund—				
£153 13s. 4d. 3½% War Loan at cost		156 5 0		
(Market Value 31st December 1948, £159)				
Cash at Bank		12 8 8	168 13 8	
Usborne Memorial Fund—				
£170 15s. 1d. 3½% War Loan at cost		174 11 1		
(Market Value 31st December 1948, £176)				
Cash at Bank		15 4 8	189 15 9	
Herbert Akroyd Stuart Fund—				
£1074 8s. 4d. 3½% War Loan at cost		1102 15 8		
(Market Value 31st December 1948, £1112)				
Cash at Bank		116 1 11	1218 17 7	
R.38 Memorial Fund—				
£1684 15s. 4d. 3½% War Loan at cost		1754 6 2		
(Market Value 31st December 1948, £1744)				
Cash at Bank		37 10 6	1791 16 8	
Edward Busk Memorial Fund—				
£453 2s. 11d. 3½% War Loan at cost		459 4 2		
£289 0s. 4d. British Transport 3% Guaranteed Stock, 1978/88, at cost		199 4 6		
(Market Value 31st December 1948, £759)		658 8 8		
Cash at Bank		14 2 4	672 11 0	
Wilbur Wright Memorial Fund—				
£1246 18s. 1d. 3½% Conversion Stock at cost		1000 0 0		
£1242 16s. 10d. 3% Savings Bonds, 1965/75, at cost ...		1250 14 9		
(Market Value 31st December 1948, £2608)		2250 14 9		
Cash at Bank		93 17 4	2344 12 1	
Simms Gold Medal Fund—				
£296 5s. 7d. 3½% War Loan at cost		304 12 0		
£200 3% Savings Bonds, 1960/70, at cost		200 0 0		
(Market Value 31st December 1948, £513)		504 12 0		
Cash at Bank		71 6 8	575 18 8	
Alston Memorial Fund—				
£252 14s. 10d. 3% War Loan at cost		250 0 0		
£38 6s. 6d. 3½% War Loan at cost		40 0 0		
(Market Value 31st December 1948, £308)		290 0 0		
Cash at Bank		21 0 5	311 0 5	
Carried forward			£143773 17 6	

Balance Sheet

	£ s. d.	£ s. d.
Brought forward		143773 17 6
Geoffrey de Havilland Memorial Fund—		
Capital Account—Donations received	4175 17 5	
Income Account—Income for year to date	66 14 6	4242 11 11
		£148016 9 5

H. ROXBEE COX, *President.*
C. F. UWINS, *Hon. Treasurer.*

REPORT OF THE AUDITORS TO THE

We have obtained all the information and explanations which to the best of our knowledge and belief were so far as appears from our examination of those books. We have examined the above Balance Sheet and annexed best of our information and according to the explanations given us the said accounts give the information required by of the Company's affairs as at 31st December 1948, and the Income and Expenditure Accounts give a true and fair Trust for the year ended on that date.

3 Frederick's Place, Old Jewry, London, E.C.2.
23*rd March* 1949.

Income and Expenditure Accounts

Royal Aeronautical Society

	£ s. d.
To Amortisation of Leasehold Property	485 0 0
„ Depreciation of Furniture	213 15 0
„ Surplus of Income over Expenditure for year transferred to Aerial Science Ltd.	3797 3 1
	£4495 18 1

Pilcher

To Income for year carried to Balance Sheet	5 7 4
	£5 7 4

Usborne

To Income for year carried to Balance Sheet	5 19 4
	£5 19 4

Herbert Akroyd

To Income for year carried to Balance Sheet	38 7 2
	£38 7 2

R.38

To 1948 Award	26 5 0
„ Surplus of Income over Expenditure for year carried to Balance Sheet	33 15 5
	£60 0 5

Edward Busk

To 1948 Award	21 0 0
„ Surplus of Income over Expenditure for year carried to Balance Sheet	4 6 1
	£25 6 1

Wilbur Wright

To 1948 Award	75 0 0
„ Surplus of Income over Expenditure for year carried to Balance Sheet	13 3 10
	£88 3 10

Simms Gold

To 1948 Award	6 17 6
„ Surplus of Income over Expenditure for year carried to Balance Sheet	10 8 2
	£17 5 8

Alston

To Income for year carried to Balance Sheet	12 6 4
	£12 6 4

Geoffrey de Havilland

To Income for year carried to Balance Sheet	66 14 6
	£66 14 6

TRUSTS LIMITED

Discrepency in pagino - Bind as is

31st December 1948—*Continued*

	£ s. d.	£ s. d.
Brought forward		143773 17 6
Geoffrey de Havilland Memorial Fund—		
£4043 16s. 11d. 3% Savings Bonds, 1965/75, at cost ... (Market Value 31st December 1948, £4165)	4175 17 5	
Cash at Bank	66 14 6	4242 11 11
		£148016 9 5

MEMBERS OF AERONAUTICAL TRUSTS LTD.

necessary for the purposes of our audit. In our opinion proper books of account have been kept by the Company Income and Expenditure Accounts which are in agreement with the books of account. In our opinion and to the the Companies Act, 1948, in the manner so required, and the Balance Sheet gives a true and fair view of the state view of the surpluses of income over expenditure of Aeronautical Trusts Ltd. and the funds administered by the

(*Signed*) PRICE, WATERHOUSE & CO.

for the Year ending 31st December, 1948

Endowment Fund

	£ s. d.
By Interest on Investments (gross)	3379 18 6
„ Interest on Investments (*less* Tax)	276 9 7
„ Refund of Income Tax 1947/48	839 10 0
	£4495 18 1

Memorial Fund

By Interest on Investments (gross)	5 7 4
	£5 7 4

Memorial Fund

By Interest on Investments (gross)	5 19 4
	5 19 4

Stuart Fund

By Interest on Investments (gross)	38 7 2
	£38 7 2

Memorial Fund

By Interest on Investments (gross)	60 0 5
	£60 0 5

Memorial Fund

By Interest on Investments (gross)	15 17 0
„ Interest on Investments (*less* Tax)	5 1 5
„ Refund of Income Tax 1947/48	4 7 8
	£25 6 1

Memorial Fund

By Interest on Investments (gross)	80 18 4
„ Refund of Income Tax 1947/48	7 5 6
	£88 3 10

Medal Fund

By Interest on Investments (gross)	17 5 8
	£17 5 8

Memorial Fund

By Interest on Investments (gross)	8 18 2
„ Refund of Income Tax 1947/48	3 8 2
	£12 6 4

Memorial Fund

„ Interest on Investments (*less* Tax)	66 14 6
	£66 14 6

OBITUARIES 1948-1949

The year has seen the death of many members of the Society. The complete list is as follows:—

E. J. N. Archbold (Associate Fellow)
W/O P. J. Baillie (Student)
F/Lt. B. Bastable (Student)
Air Cmdre H. G. Brackley (Fellow)
Col. W. A. Bristow (Fellow)
S/Ldr. S. T. Carpenter (Associate Fellow)
J. E. Creigier, Jr. (Associate)
L. W. Crowther (Associate Fellow)
F. H. Dixon (Associate)
W. A. Edwards (Associate)
Sir W. Lindsay Everard (Companion)
L. Field (Associate Fellow)
D. R. Garraway (Student)
P. W. Howes (Associate Fellow)
H. E. Hudson (Associate Fellow)
F/Lt. G. H. Hull (Associate Fellow)
V. O. Levick (Associate Fellow)
C N. H. Lock (Fellow)
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F/Lt. W. J. McMeekan (Associate)
Capt. J. C. McPhee (Associate)
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C. W. Smith (Associate)
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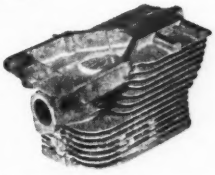

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NOTICES JULY 1949

CLOSING OF THE SOCIETY'S OFFICES

The offices of the Society will be closed from 2nd to 18th July 1949 for redecoration. The offices will also be closed on Saturday, 30th July and August Bank Holiday, Monday, 1st August 1949.

CONTENTS OF THE JULY JOURNAL

Council 1949-50.

The Society's Medals and Awards.

The 37th Wilbur Wright Memorial Lecture—The Aeronautical Research Scene—Goals, Methods and Accomplishments, by Hugh L. Dryden, M.A., Ph.D., F.R.Ae.S., Hon.F.I.Ae.S.

Planned Servicing in the Royal Air Force, by Squadron Leader E. A. Harrop, O.B.E., A.F.R.Ae.S.

The Eighty-fourth Annual Report of Council 1948-1949.

The Council have set aside an annual sum of £250 for the award of premiums for papers published in the Journal and hope that members (or non-members) will contribute papers on their own special subjects.

THE SOCIETY'S MEDALS AND AWARDS

Changes have recently been made in the terms of reference governing the Society's Medals and Awards. A complete list of the Medals and Awards with the new terms of reference is given on page 622 of the July JOURNAL.

A CORRECTION

We regret that in the May Monthly Notices M. Louis Breguet, who was awarded Honorary Fellowship of the Society, was inadvertently described as President of A.F.I.T.A. M. Breguet is head of the French aircraft company which bears his name and he is a member of A.F.I.T.A. The President of A.F.I.T.A. is of course M. J. Jarry, F.R.Ae.S.

AIRPORT PAPERS

The papers read by P. H. Watson and C. E. Foster at the Joint meeting of the Airport Engineering Division of the Institution of Civil Engineers and the Society on 22nd March 1949, together with the Discussion, will be published in the Institution Journal for October 1949. Reprints will be available at 2s. 0d. each.

The papers read were:—

Aircraft Design with Special Reference to the Restriction Imposed by Considerations in Airfield Design, by P. H. Watson, B.Sc., A.F.R.Ae.S., and

The Problem of Airfield Design in Relation to Aircraft Design, by C. E. Foster, C.B.E., B.Sc., A.M.I.C.E.

ASSOCIATE FELLOWSHIP EXAMINATION, DECEMBER 1949

Candidates are reminded that the December examination will be the last date on which papers will be set in the old syllabus. Papers are still available for the past four years at 2/2 per set (including postage). Entry forms, with fees, must be received by 30th September 1949, but it would help the organisation of the examinations if candidates would inform the Secretary as soon as possible of their

intention of taking the examination. Entries for the new Syllabus must be received by 31st August 1949.

THE AERONAUTICAL QUARTERLY

The Council have great pleasure in announcing that the first number of *The Aeronautical Quarterly* is now available. Copies may be obtained from the offices of the Society, 4 Hamilton Place, W.1, at 7/9 each to members of the Society or 10/3 each post paid to non-members.

The contents of the first number are:—

Control Reversal Effects on Swept-back Wings	H. Templeton
Calculation of Downwash Behind a Supersonic Wing ..	G. N. Ward
Estimation of the Effects of a Parameter Change on the Roots of Stability Equations	K. Mitchell
Flutter of Systems with Many Freedoms	W. J. Duncan
Note on Propeller-Turbine Reduction Methods	E. C. Pike
Determination of the Drag of Jet-Propelled Aircraft in Flight	G. W. Trevelyan and D. R. Blundell
Notes on the Linear Theory of Incompressible Flow Round Symmetrical Swept-back Wings at Zero Lift	F. Ursell

GRADUATES' AND STUDENTS' SECTION

VISIT: Wednesday, 10th August 1949.—High Duty Alloys Ltd., Slough, Bucks, at 1 p.m. Members of the Section who wish to be included in the visit should inform the Assistant Hon. Secretary, D. A. Thurgood, Sunnyside Bungalow, Ripley, Surrey, not later than *2nd August* 1949.

JOURNAL BINDING

The prices for binding of Journals are as follows:—

1948 Volume	14s. 6d.	(including packing and postage)
Previous Volumes ..	16s. 0d.	,, ,, ,, ,,
Cases for 1948 Volume	6s. 0d.	,, ,, ,, ,,

Journals should be sent direct to the Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the Offices of the Society.

Requests for cases, with remittances, should be sent to the Secretary at the Offices of the Society.

CHANGES OF ADDRESS

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).
Grade of membership.
New address (in block letters).
Old address.

Changes of address must be received *before the 15th of the month* in order to be effective for the Journal for the following month.

NEW MEMBERS

The following new members have been elected:—

Fellows

Edgar Hilton Atkin (from Associate Fellow), James Valentine Connolly (from Associate Fellow), Percy George Crabbe (from Associate Fellow), Arthur Ernest Hagg, Robert Ernest Hardingham (from Associate Fellow), William Henry Lindsey

(from Associate Fellow), John Lloyd, Basil Gervase Markham (from Associate Fellow), David Macleish Smith (from Companion), Richard Walter Walker (from Associate Fellow).

Associate Fellows

Frank Ashton (from Graduate), Frank Camfield Aylesbury (from Associate), Gilbert William Beesley, Graham Brook Bell (from Associate), Edmond Antoine Sylvestre Brun, Paul Cadman (from Graduate), Arthur Capella (from Graduate), Richard Connor, John Edward Curtis (from Graduate), William Deacon, John William Glanfield, Reginald Maurice Gray, Gordon Lander Gunstone (from Student), John Ernest Haines (from Graduate), Manning Harris, Ronald Owen Hender (from Associate), Cyril Francis Holloway (from Associate), Horace Tom Elliott Hone (from Graduate), John Bernard Everett Keeble (from Associate), Richard Norman Kemp (from Graduate), Yehuda Kritchevsky (from Companion), Cyril William Lawrence, Dennis Lean, Anthony Brian Davies Leigh (from Graduate), Daniel Llewellyn, Sidney Walter Douglas Lockwood, Ian Alfred Thomas Lumsden (from Graduate), Philip Raymond Martin, John Bush Matthews, Edward Frank Mitchell (from Graduate), Kenneth Harold Oosterlaak, Earl Pine Osborn, Joseph Rimmington, David Sadler (from Graduate), Peter Edward Saunders (from Graduate), Max Olivey Scott, Charles Frederick Smart, Bernard Hugh Stanley (from Graduate), Robert Henry Stevens (from Graduate), Ernest Knightley Wellsted, Robert Michael Wingate (from Student), Herbert Wager Winterbottom (from Graduate), John Leonard Wood (from Graduate), George Young.

Associates

Arthur Frederick Childs, William Henry Gray Wishart Finlay, Leslie Griffiths, George Aaron Hargrave, Frederick John William Harwood (from Student), Donald William Kemp (from Student), Alfred Walter Liquorish (ex-Student), Charles Geoffrey Miller (from Student), Robert Vernon Moxey, Thomas Victor Orgill, Kenneth McLean Park (from Student), Ronald Alfred Pearson, William Edward Plummer, Reginald William Macer Sennitt, Oswald Thomas Shorthouse, Arthur Edward Slocombe, Herbert Charles Taylor, Peter Ignatius Taylor, Andrew Waugh, Albert Cyril Wilson.

Graduates

Sydney Edward Adams, Frederic Bedrich Adler, David George Baker (from Student), M. S. Balasubramanian (from Student), Rowland John Barnard, Derek George Brown (from Student), Derek Stuart Capps, Leslie Maurice Carlile (from Student), William Harry Casley, Arthur Cecil Ronald Collins, William George Corbett (from Student), Thomas Norman Corkill (from Student), Peter Davenport (from Student), Joan Lidster Davis (from Student), Edward R. Geargeoura, Roy Michael Gibson, Alan Geoffrey Rolfe Gilbert, John Robert Hair, Thomas Leonard Hall, Alan Roy Hammond (from Student), Kenneth Thomas Jackson, Gordon Ernest Jervis, Jacek Kundycki, K. Kwiatkowski, Alkis N. Lagopoulos, Peter Richard Lodge, Colin Sidney Ritchie Marshall, Alec Measures (from Student), Hans Hermann Neustadt, Geoffrey Herbert Nixon, Bryan Rex Noton (from Student), James George Alexander Paterson (from Student), John Charles Henry Peaker, Jack Phillips, Alan Powell (from Student), William John Rainbird, Alan Middleton Rawlings, Josef Rosenthal, Robert Loosemore Scotland, John Anthony Scott (from Companion), Arnold John Sobey, Cyril William Soley, Keith Donald Thomson (from Student), Donald Francis Vowles.

Students

Gerard Edmund David Bonham-Carter, Reginald Guy Boor, Francis Henry Borlace, Trevor Gerald Evans, Victor Nigel Ferriman, Victor Albert Hindley, Daniel John Holding, John Frederick Jones, Raymond Charles McNamara, Thomas Timothy Mehigan, John Desmond Penrose, Robert Victor Read, John Albert Ross, Robert John Saker, Ian Thompson Smyth, Richard James Starling.

Companion

Trevor Stratton Braybrooke (from Graduate).

ACKNOWLEDGMENTS

The Council acknowledge with grateful thanks the gift of Lantern Slides from Lord Brabazon, Honorary Fellow, and back numbers of the JOURNAL from A. M. Desoutter, Associate Fellow, and Mrs. M. B. Leak.

ADDITIONS TO THE LIBRARY

Pamphlets in italics with location reference following in brackets. Books marked * or ** may not be taken out on loan.

A.c.19—Gas Tables. J. H. Keenan and J. Kaye. John Wiley, New York. 1948.
BB.b.143—Machine Design. Paul H. Black. McGraw Hill. 1948.
D.c.119—Airport Management. J. H. Frederick. Richard D. Irwin. U.S.A. 1949.
E.f.117—Aircraft Power Plants. Northrop Aeronautical Institute. McGraw Hill, New York. 1948.
E.g.12—Hydraulic Machinery. S. R. Beitler and E. J. Lindahl. Irwin-Farnham, U.S.A. 1947.
F.b.45—Petroleum Handbook. Shell Petroleum Company. 1948.

N.A.C.A. Technical Memoranda

1203—*The compressible flow past various plane profiles near sonic velocity. B. Gothert and K. N. Kawalki.*
1204—*Some new problems on shells and thin structures. V. S. Vlasov.*
1208—*Calculation of counterrotating propellers. F. Ginzel.*
1210—*Development of spoiler controls for remote control of flying missiles. G. Ernst and M. Kramer.*
1211—*The characteristics method applied to stationary two-dimensional and rotationally symmetrical gas flows. F. Pfeiffer and W. Meyer-Konig.*
1215—*Flow pattern in a converging-diverging nozzle. Kl. Oswatitsch and W. Rothstein.*
1216—*An approximate method for calculation of the laminar boundary layer with suction for bodies of arbitrary shape. H. Schlichting.*

College of Aeronautics, Cranfield

26—*On the natural frequencies of a reinforced circular cylinder. W. S. Hemp.*
27—*Some related oscillation problems. W. J. Duncan.*

N.A.C.A. Technical Notes

1233—*Preliminary analysis of N.A.C.A. measurements of atmospheric turbulence within a thunderstorm—U.S. Weather Bureau Thunderstorm Project. H. B. Tolefson.*
1508—*Provisional symbols and definitions for aircraft turbines. N.A.C.A. Sub-Committee on Turbines.*
1770—*Office of Naval Research and N.A.C.A. metallurgical investigation of a large forged disc of Inconel X alloy. H. C. Cross and J. W. Freeman.*
1817—*Plastic buckling of simply supported compressed plates. R. A. Pride and G. J. Heimerl.*
1832—*Small bending and stretching of sandwich-type shells. E. Reissner.*
1834—*The influence of blade-width distribution on propeller characteristics. E. G. Reid.*
1835—*Investigation at low speeds of the effect of aspect ratio and sweep on rolling stability derivatives of untapered wings. A. Goodman and L. R. Fisher.*
1838—*Dynamometer-stand investigation of a group of mufflers. D. D. Davis, Jr. and K. R. Czarnecki.*

1840—*Analysis of properties of foam. J. W. McBain, S. Ross and A. P. Brady.*
1841—*Quantitative study of variations in concentration of glycerol and aerosol OT on foaming volume of oil at room temperature. J. W. McBain and S. Ross.*
1842—*Control of foaming by adding known mixtures of pure chemicals. J. W. McBain, S. Ross, A. P. Brady and R. B. Dean.*
1843—*Effect of various compounds in use with airplane engines upon foaming of aircraft lubricating oils. J .W. McBain and W. W. Woods.*
1844—*Surface properties of oils. J. W. McBain and J. V. Robinson.*
1845—*Attempts to defoam existing oils by processing. J. W. McBain, J. V. Robinson, W. W. Woods and I. M. Abrams.*
1848—*Flutter of a uniform wing with an arbitrarily placed mass according to a differential-equation analysis and a comparison with experiment. H. L. Runyan and C. E. Watkins.*
1851—*Critical shear stress of infinitely long, simply supported plate with transverse stiffeners. M. Stein and R. W. Fralich.*
1853—*Effect of increase in afterbody length on the hydrodynamic qualities of a flying boat hull of high length-beam ratio. W. J. Kapyran and E. P. Clement.*
1855—*Recommended values of meteorological factors to be considered in the design of aircraft ice-prevention equipment. A. R. Jones and W. Lewis.*
1863—*Comparative strengths of some adhesive-adhered systems. N. J. DeLollis, N. Rucker and J. E. Wier.*

N.A.C.A. Technical Reports

835—*Properties of low-aspect-ratio pointed wings at speeds below and above the speed of sound. R. T. Jones.*
837—*Standard nomenclature for airspeeds with tables and charts for use in calculation of airspeed. W. S. Aiken, Jr.*
841—*Application of the method of characteristics to supersonic rotational flow. A. Ferri.*
851—*Thin oblique airfoils at supersonic speed. R. T. Jones.*
856—*The N.A.C.A. high-speed motion-picture camera optical compensation at* 40,000 *photographs per second. C. D. Miller.*
859—*Measurements in flight of the pressure distribution on the right wing of a pursuit-type airplane at several values of mach number. L. A. Clousing, W. N. Turner and I. S. Rollin.*
862—*An investigation of a thermal ice-prevention system for a twin-engine transport airplane. A. R. Jones.*

C.S.I.R. Division of Aeronautics

Report E.63—*Aerodynamic lift and moment for oscillating aerofoils in cascade. A. E. Billington.*

National Research Council of Canada

*Quarterly Bulletin, Report No. ME.*1949 (1), *January-March* 1949.

Publications Scientifiques et Techniques du Ministere de l'Air

225—*Détermination et calcul des hélices d'avions optima, simple et coaxiales. R. Hirsch.*

Royal Institute of Technology, Stockholm

KTH-AERO TN 2—*An investigation of the effect of boundary layer suction on the air resistance in channel elbows. H. O. Palme.*

J. LAURENCE PRITCHARD,
Secretary.

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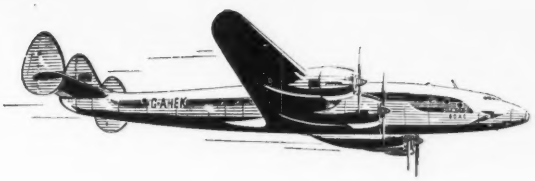

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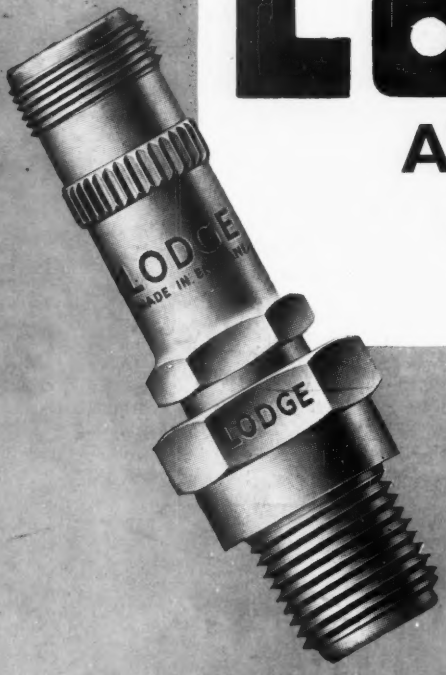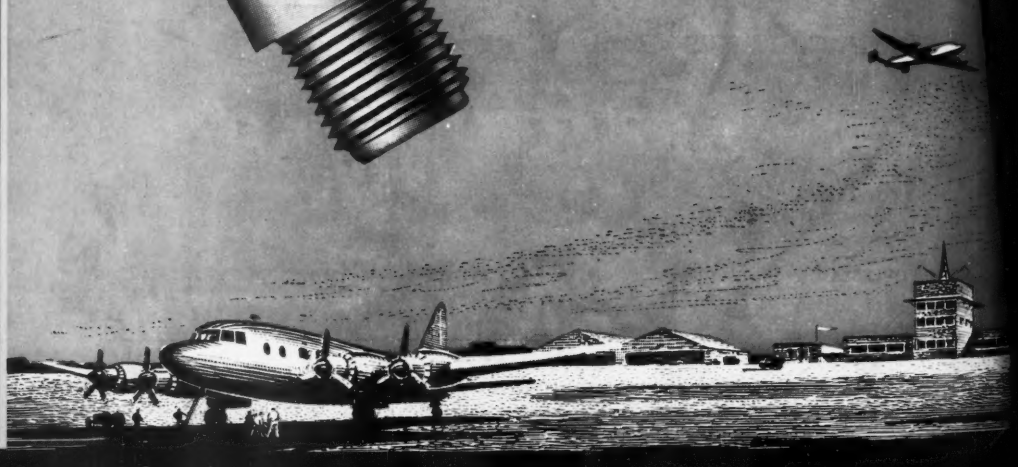
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